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HUDSON LABORATORIES of Columbia University

145 Palisade Street, Dobbs Ferry, N. Y. 10522

TECHNICAL REPORT No. **167**

PROJECT APTERYX: FINAL REPORT (U)

SEP 25 1969

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by

DDC CONTROL NO. 93021

Wilton A. Hardy

March 1969

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Hudson Laboratories
of
Columbia University
Dobbs Ferry, New York 10522

Technical Report No. 167

PROJECT APTERYX: FINAL REPORT

(Hudson Laboratories Operation 245)

by

Wilton A. Hardy

SECRET

March 1969

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NO.

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of 112 pages

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ABSTRACT

Long-range propagation measurements were carried out in the South Pacific Ocean as Project APTERYX. This report summarizes the data obtained on board the USNS J. W. Gibbs for the detection of acoustic signals from the areas of New Zealand and the Hawaiian Islands.

I. INTRODUCTION

In the fall of 1966 Dr. Alan Berman, Director of the Long Range Underwater Sound Coordinating Committee, was requested by the Department of Defense to study long range sound propagation over the major water masses of the Pacific Ocean. Emphasis was to be placed on the coupling of surface or near surface sources to the dominant sound channels that exist in the Pacific and thus, and with orientation toward underwater surveillance, to obtain an indication for future strategic planning as to the location of favorable sites for acoustic monitoring.

The request constituted a forward area research evaluation of the Pacific Ocean to provide preliminary data that would yield a technical basis for establishing guidelines for long range acoustical propagation and its excitation and detection. Initial experiments in these directions had been carried out in the northern Pacific, i. e., roughly, the waters north of Hawaii, as part of the TRIPLE EOS series of investigations and also as tests undertaken by COMOCEANSYSPAC. Scant data were available, however, for the acoustically unexplored central and southern Pacific Oceans. Also, the Department of Defense sought specific guidance as to the long term possibility of surveillance stations located on the western coast of South America. Efficient propagation to this region would not be unexpected in view of the dominant sound velocity profiles found in this area, e.g. Fig. 1, that show a strong surface thermocline and a well-defined sound channel which can act as a low-attenuation duct for low-frequency sound.

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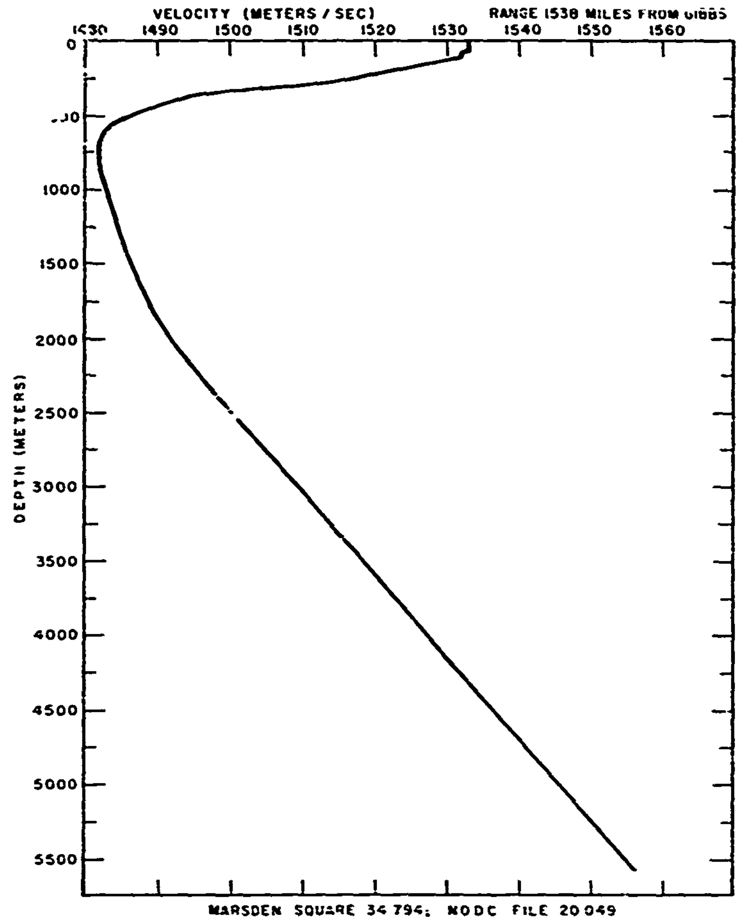

Fig. 1. Typical sound velocity profile for the southern Pacific Ocean in waters off the western coast of South America.

Velocity profile and bathymetric data for the central southern Pacific Ocean are very limited. This indicated that a broad-scale experiment that tested the acoustical transmission directly could give the promptest answer to the Department of Defense, pending reliable data surveys which would provide accurate environmental data to serve as a basis for predictive models. For this reason also, very long range transmission paths were emphasized - the demonstration that these paths exist with transmission losses comparable to those that have been investigated in the Atlantic becomes a primary datum in planning more specific surveillance systems for the future.

The overall plan of the experiment that was developed for this purpose is indicated in Figs. 2-5. Three primary operational areas are shown:

	Code	Area
1.	HW	Southwest of the Hawaiian Chain
2.	NZ	The southern Pacific east of New Zealand, and
3.	GA	The Pacific off the western coast of South America and south of the Galapagos Islands.

The acoustical transmission paths tested were:

i) within the operational areas of HW and NZ, above,

ii) between the three operational areas, and

iii) from the area of HW to the western North American coast.

Participating laboratories or commands were:

1. The New Zealand Naval Research Laboratory (NRLNZ), which provided and monitored listening stations on the Mahia Peninsula and also generated explosive shots in the Pacific east of New Zealand from the RNZFA TUI and aircraft of the New Zealand Air Force.

2. Scripps Institution of Oceanography (MPL), which provided and monitored the research station FLIP at a location south of Hawaii.

3. Hudson Laboratories working from the USNS J. W. Gibbs (T-AGOR-1), which generated explosive shot sources and cw signals from a towed projector west of South America and also monitored the other source events from two anchor positions in that area.

4. COMASWFORPAC, which coordinated aircraft explosive shot drops with FAIRWINGSPAC and VP-6 and also obtained bathythermograph data over principal propagation paths near Hawaii.

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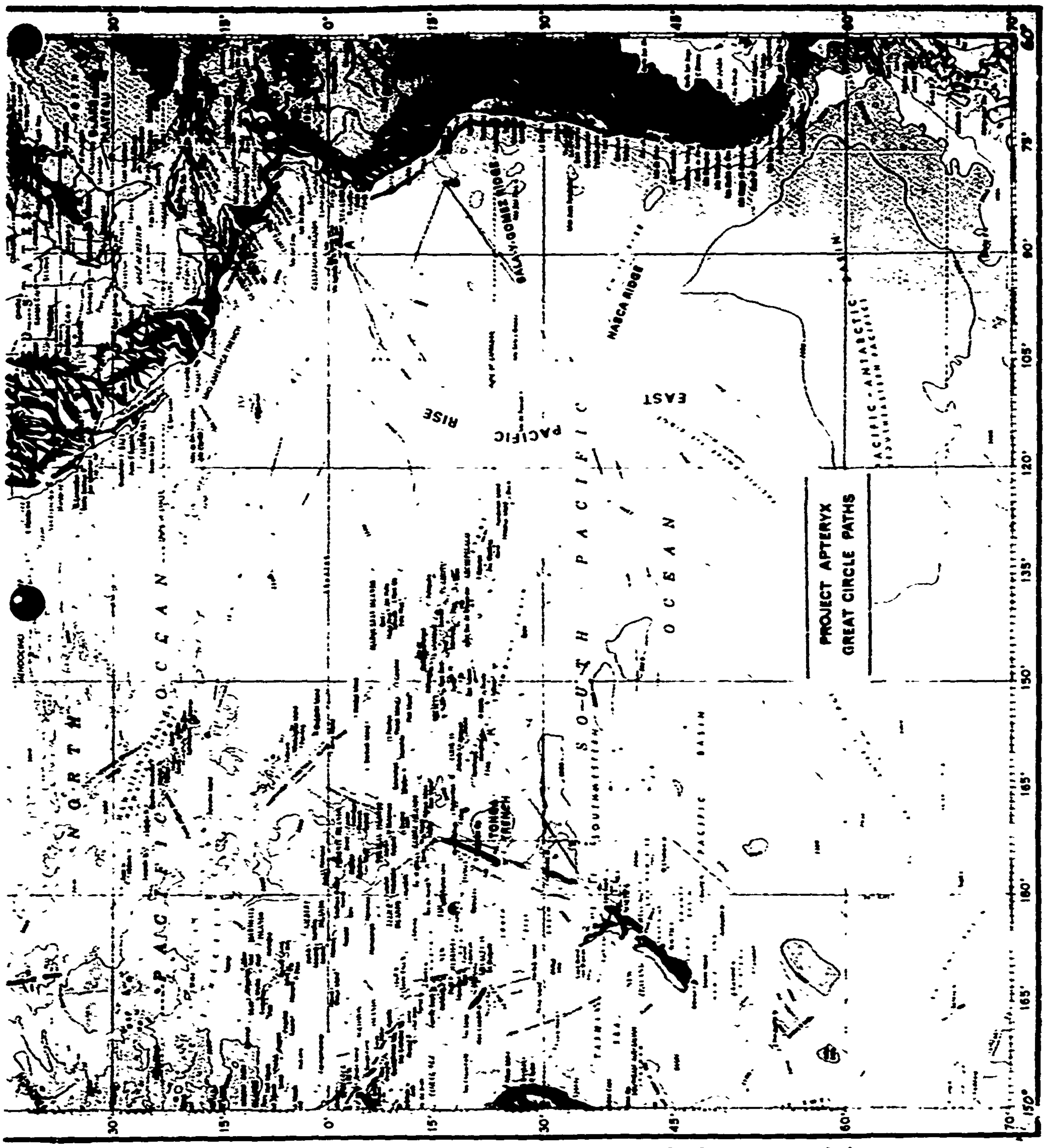

Fig. 2. Chart for the Pacific Ocean indicating major bathymetry and the Hawaiian, New Zealand, and South American operational areas for Project APTERYX.

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Fig. 3.

Regional areas of the APTERYX experiment. In the NZ area NRLNZ established a hydrophone listening station and provided both ship- and aircraft-dropped explosive shots. In the GA area the USNS J. W. Gibbs established two listening stations and provided a projector tow at 100 Hz and a series of explosive shots over the indicated tracks. In the HW area listening stations were established by FLIP and the Pacific MILS hydrophones were also monitored. Sources in the HW area consisted of aircraft-dropped shots; the tracks for these drops are shown in Fig. 4.

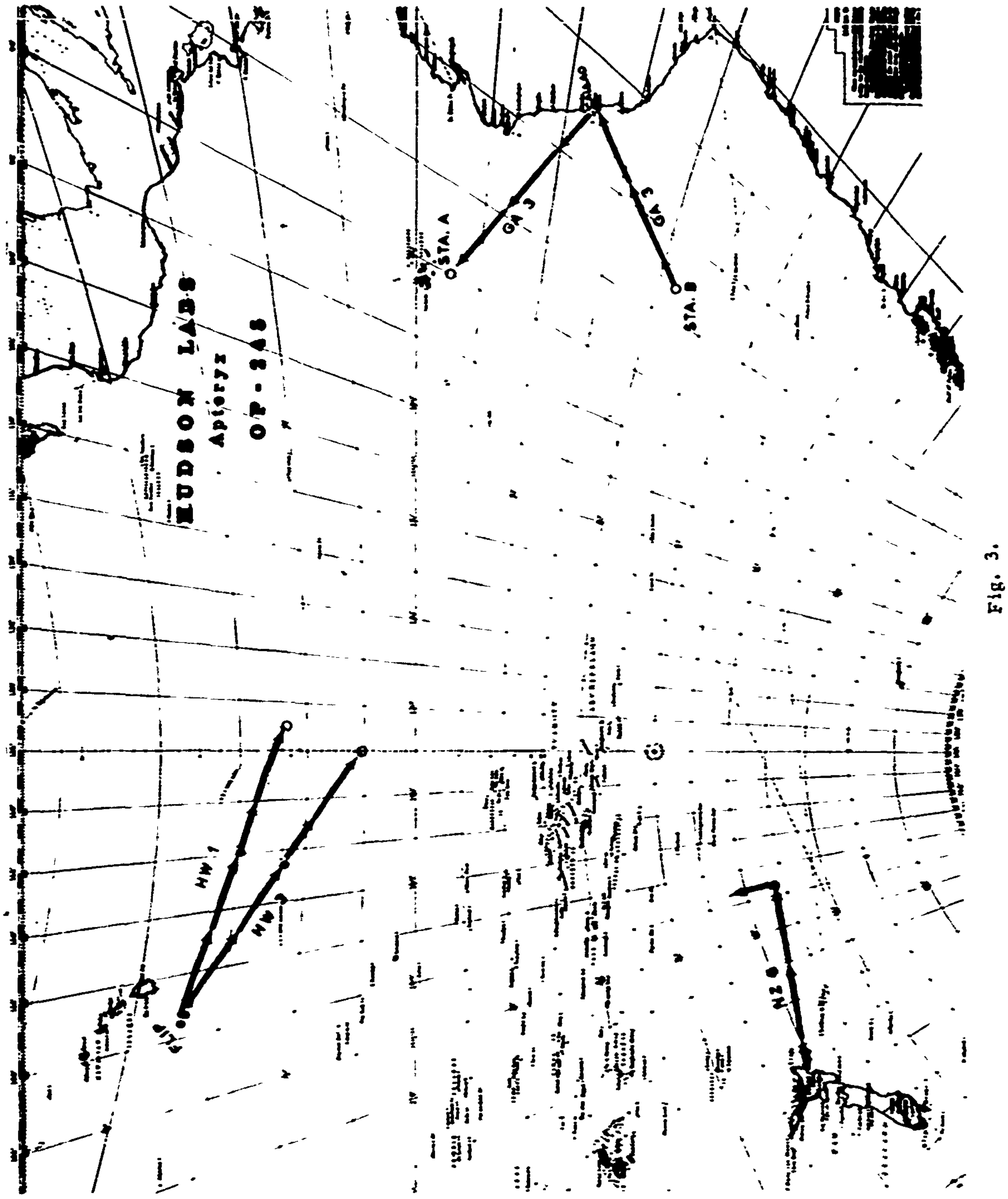

Fig. 3.

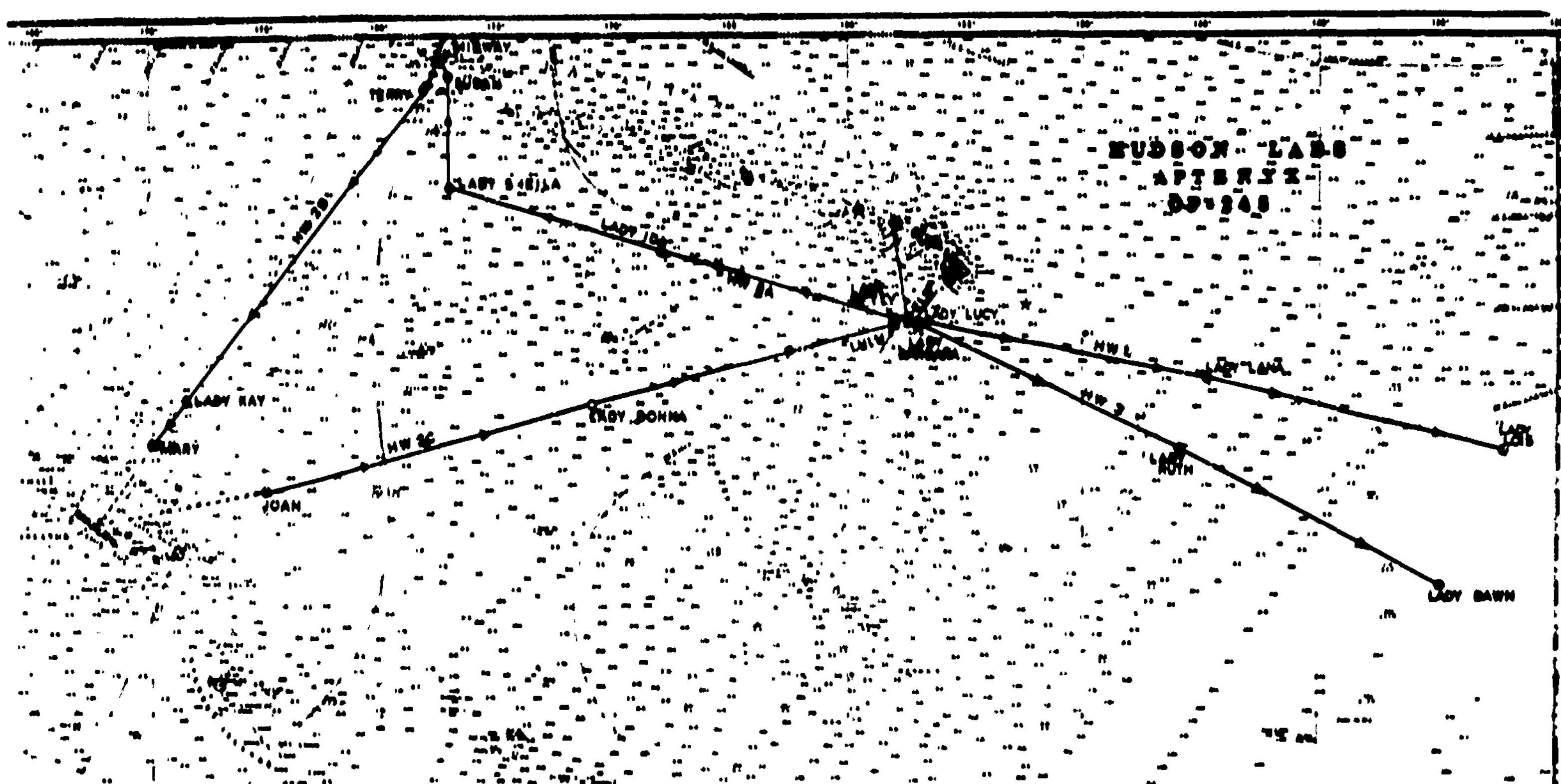

Fig. 4. HW area. Flight plan for aircraft-dropped Mk 61 PDC charges at 2-min (8 mile) intervals with explosion depths which alternate between 60 ft and 800 ft. At the positions designated "LADY ..." a Depth Shot Sequence was established using Mk 59 SUS charges at the depths 300, 1000, 2000, 3000, 4000, 6000, and 10,000 ft.

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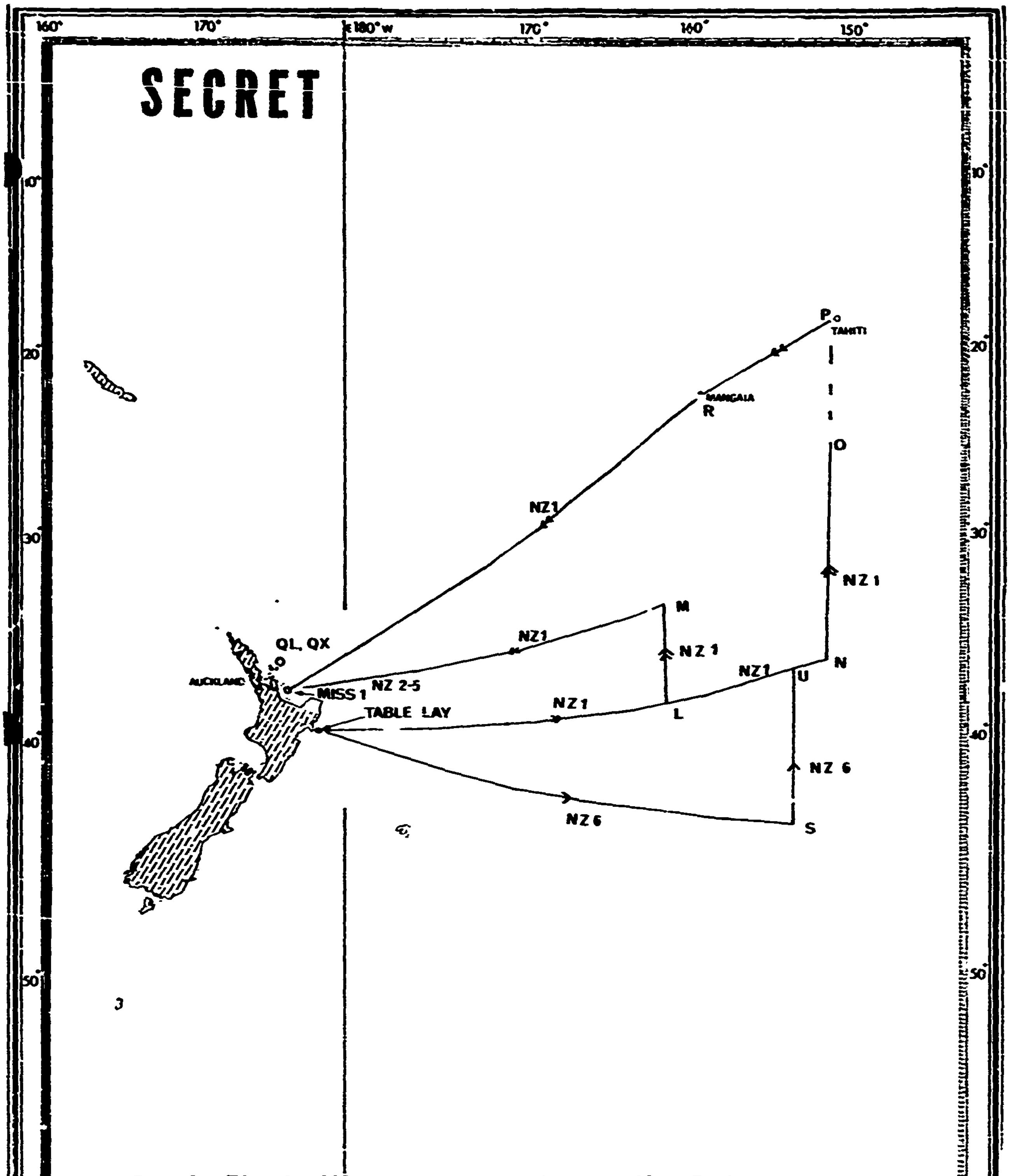

Fig. 5. Plan for NZ area source tracks using New Zealand aircraft and the RNZFA TUI, and showing the positions of the monitoring stations TABLE LAY and MISS 1.

5. COMOCEANSYSPAC, which recorded shot transmission data at Pacific Coast SOSUS stations from air-dropped shot sequences near Hawaii.

6. PACIFIC MISSILE RANGE, which monitored the source events detected on MILS hydrophone stations in the Pacific.

7. NAVOCEANO, with the responsibility for data analysis of the records obtained at COMOCEANSYSPAC and certain of the MILS stations.

In recognition of the contribution and participation by the New Zealand Naval Research Laboratory, the overall experiment was given the code name, Project APTERYX. Appendix A of this report gives the operational order for the experiment. This was supplemented by individual operational orders of the participating groups. During the experiment, minor schedule changes were required but, and thanks to the cooperation that existed among all groups throughout the operations, all of the acoustic events were performed and all monitoring stations were established and recorded data.

The ship's track of the USNS J. W. Gibbs (Hudson Laboratories) is shown in Fig. 3 for the GA area, the aircraft tracks and the location of the FLIP monitoring station (SCRIPPS) are shown in Fig. 4 for the HW area, and the New Zealand "Table Lay" monitoring station and the tracks of the ship RNZFA TUI and New Zealand aircraft are shown in Fig. 5 for the NZ area. It was agreed that the reduction and preparation of the data obtained by the participating groups would be carried out by the individual laboratories and would be published separately by these laboratories.

II. THIS REPORT - PARTICIPATION OF HUDSON LABORATORIES ON THE USNS J. W. GIBBS (T-AGOR-1) - SUMMARY

This report summarizes the data obtained by Hudson Laboratories on board the USNS J. W. Gibbs, in its participation in Project APTERYX, by monitoring the acoustic reception at two anchor stations off the west coast of South America. In transit between these two stations the Gibbs also served as a source ship for a tow of a cw projector and as a source for a series of explosive shots. The acoustical paths tested were those between the Pacific coast of South America across the South Pacific Ocean to New Zealand, and also those across the equator to the Hawaiian Islands, c.f. Fig. 2.

The results of these tests, presented later in this report, show that transmission loss magnitudes ranging from less than 110 dB to 120 dB can be obtained for ranges from 2500 nautical miles (n.m.) to over 5000 n.m. This corresponds to pure cylindrical spreading of the sound field, modified by a frequency dependent absorption given by an attenuation factor $10^{-\alpha R}$ where $\alpha = \frac{a}{f} + b + cf$ and with the frequency f measured in Hertz and the range R measured in n.m. Numerical values for the constants have been found to be: $a < 0.08$, $b = 1.6 \times 10^{-3}$, and $c = 3.5 \times 10^{-5}$ (For 100 Hz and 1000 n.m. range, this results in an attenuation of only 5.9 dB.) Certainly, these must be accepted as low-loss transmission paths.

However, it must be emphasized that under the conditions of the experiments these losses represent propagation in the Pacific sound channel. Although it is useful to know that these low-frequency, low-attenuation acoustical paths exist, what is important for surveillance applications is not

this fact but the degree by which both surface or near-surface sources and a set of emplaced hydrophones can couple to the low-loss, sound channel mode of propagation. This point has been emphasized by A. Berman and has been demonstrated by many experiments, e.g., those of the TRIPLE EOS and BOOMERANG series, which were initiated under his direction.

Long-range detections of surface or near-surface sources do become feasible when the sound velocity profiles change in structure to allow efficient conversion of the sound field from the surface into sound channel propagation. This process can be predicted quantitatively, and with good precision, by computer programs that have high capacity for the storage of detailed sound velocity data and the ability to follow the effects of the changing velocity profile structure with range. (A specific example of this prediction, using the APTERYX data, is given later in this report.) It does follow that when suitable oceanographic environmental data are available, reliable predictions can be made that define the propagation loss limits that will apply to specific surveillance installations. A key requirement of the programs is that they define the depth dependence of the transmission loss in the velocity profile structures of the surveillance area.

The above conclusions must be modified, often profoundly, when underwater terrain can obstruct the sound field or, acting favorably, can accentuate the sound field via a limited number of bottom reflections. The acoustical paths measured in APTERYX crossed the East Pacific Rise, which can be characterized primarily as a broad rise with an average depth of approximately 1500 fathoms. As a result, the Rise acted to limit the aperture for the sound field propagating across it so that the transmission was entirely confined to the sound channel existing above the Rise. Because of the breadth

of the rise, the deeper components of the sound field become completely attenuated in their transit. Also, the sources and receivers of APTERYX were located at large distances from the Rise so that, and due to diffraction, the effect of individual seamounts that might exist on the Rise would not be expected to produce significant attenuation any more than, say, some dust specks on a camera lens markedly affect the film illumination.

Nonetheless, the limiting of the sound channel aperture by the East Pacific Rise affects the depth dependence of the spreading sound intensity not only at the bottom but in the upper surface waters. This can be seen from the sound velocity profile of Fig. 1 in which the sound velocity at the depth of 300 m becomes equal to the sound velocity at a depth of 3050 m. By aperture of the sound channel we mean that depth interval within which the wave energy is trapped about the sound channel axis and is highly attenuated outside that depth interval. This restriction implies that there is very poor coupling between surface or near-surface sources that lie above the aperture for propagation in the sound channel.

The measurements made from the Gibbs during APTERYX indicate that the observed propagation was due primarily to sound channel propagation in a horizontal duct of a limited depth interval that extends from at least 500 ft below the sea surface to a depth of the order of 6000 to 8000 ft. This depth interval applies both to the excitation of sound in the channel and to the positioning of listening hydrophones for detection.

A specific conclusion is that the Pacific Ocean area from the East Pacific Rise to the coast of South America is not favorable for the location of sites for the acoustic surveillance of sources whose depth is of the order of 500 ft or less and which are searched for in the Pacific Ocean <u>west</u> or

northwest of the East Pacific Rise. Further, the detection of sources at depths of 500 ft or greater would require that the receiving hydrophones be positioned within the sound channel for efficient detection.

The evidence for these conclusions is as follows:

1. At no time during APTERYX were any long-range acoustic signals received on hydrophones located on the bottom, at depths of 2315 and 1820 fathoms, although local tests showed these hydrophones to be in good working condition and with very low noise background.

2. All detections were made by hydrophones near the sound channel axis, at depths of 2000 or 3300 ft. Although hydrophones were emplaced at depths of 500 and 1000 ft, no clear detection of signals was recorded with these units.

3. Explosive charges fired in depth sequences during APTERYX enabled tests to be made of the dependence of the excitation of the sound as a function of the charge depth. From the New Zealand area no signals were detected at the Gibbs for excitation depths less than 800 ft, and the sources at this depth were 300-lb depth charges. During a 50-min period (200 miles) of the Serial HW-1 only, 1.8-lb PDC charges were detected for a firing depth of 60 ft, but all other detections from the Hawaiian area were made for source depths of 800 ft or greater.

4. During APTERYX, only two explosive shots at a depth of 10,000 ft were detected and these were highly attenuated with respect to the other shots placed in the sound channel. This indicates the confinement of the propagation to a horizontal stratum with a deeper depth limit that is less than 10,000 ft.

5. Even for the most favorable emplacement of both source and hydrophone in the sound channel, the transmission losses were -105 dB or

worse. The transmission loss was a sensitive function of frequency, having minimum magnitude at about 30 Hz and dropping off with frequency thereafter according to the attenuation quoted previously. An optimum depth for low-frequency excitation is in the depth interval from 1500 to 6000 ft, with rapidly increasing attenuation as the surface is approached.

6. By the reciprocity law, equivalent transmission losses will be obtained if the positions of sources and detectors are reversed. Reports of the monitoring by the Hawaiian and New Zealand hydrophone stations of the acoustic sources from the Gibbs indicate that the only significant detections of explosive shots were those from sources with depth of excitation in the sound channel. The cw projector, at 110 Hz, was not at all detected by New Zealand even at the depth of 500 ft and a 98-dB source level. The projector was detected intermittently · Hawaii by MILS hydrophones in the sound channel for a source depth of 300 ft and a 95-dB source level.

The above conclusions and further data given in this report are based upon the data gathered and interpreted both in the field on board the Gibbs and from data tape playback at Hudson Laboratories.

III. SYNOPSIS OF MAJOR EVENTS: USNS J. W. GIBBS

A. Location of Site "B" (20°41' S, 83°14' W)

A number of limitations, including transit time restrictions, did not permit the Gibbs to attempt a listening station on the western side of the East Pacific Rise. Prior to the experiment, therefore, a search was made of the available bathymetric information off the Pacific coast of South America to determine whether a suitable rise could be found that would permit the establishment of a bottom hydrophone at a depth of the order of 1600 fathoms or

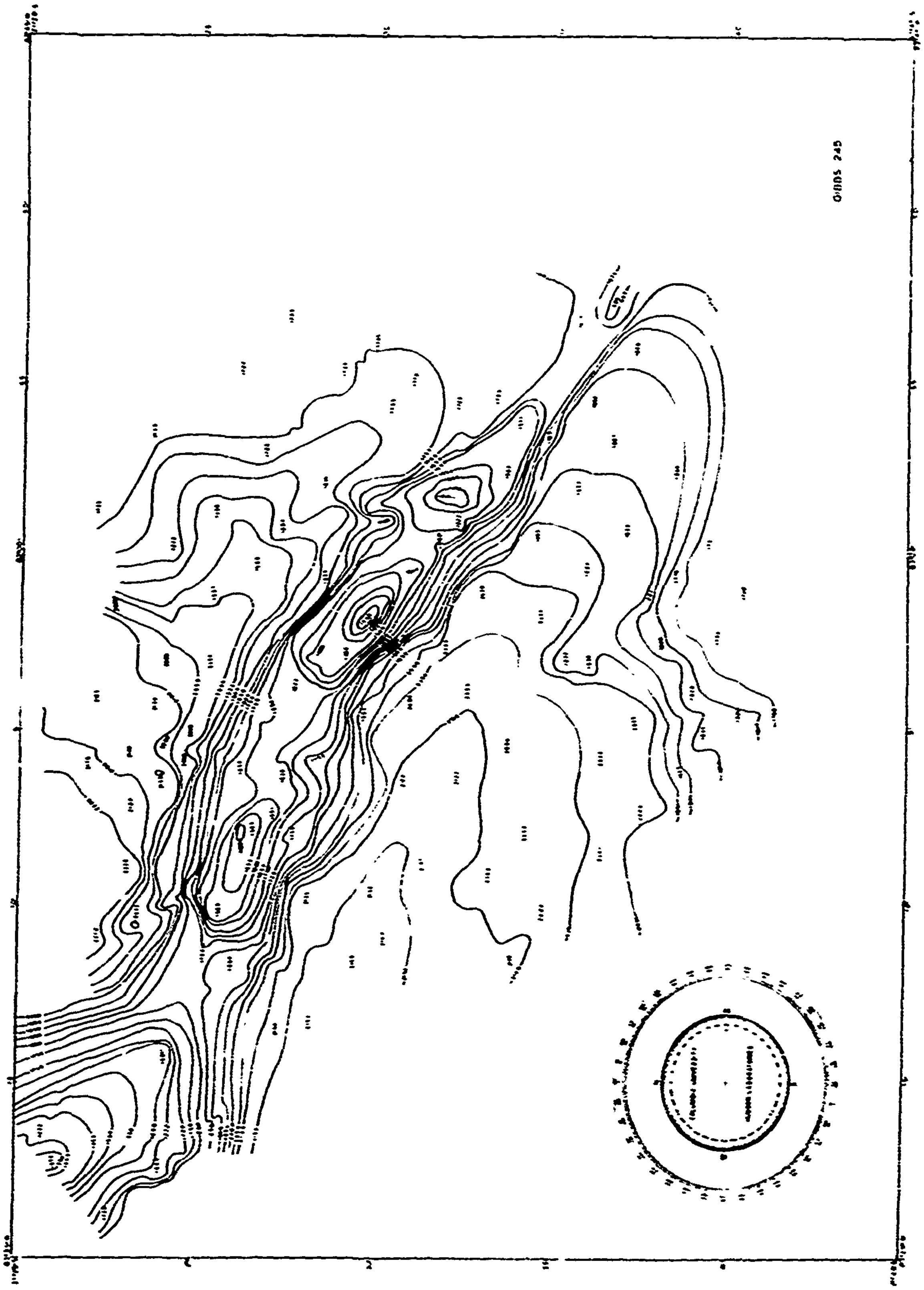

Fig. 6. Bathymetry at GA site "B" specified prior to experiment. In the original report (Ref. 1) an overlay is provided to indicate the ship's tracks during the survey.

less. Although there is little accurate bathymetric data for this area it was indicated that a 1650-fathom seamount existed at 21°30' S, 83°00' W and this location was selected as site "B" as a first listening location. Site "B" also showed clear acoustic paths to both New Zealand and the Hawaiian areas except for the East Pacific Rise.

On arrival at site "B" (February 19, 1500Z) the Gibbs began a semi-detailed bottom survey that indicated extremely mountainous bottom terrain with slopes of 20° being common. The location was unsuitable either for acoustical monitoring or for anchoring. As this became clear from the initial survey a further search was made for a better site. It was unfortunate that the tight schedule requirements of APTERYX did not permit greater investigation of the bottom, but such research had to take second priority to the responsibility of finding a suitable anchoring location for the ship. The scheduled site "B" area is shown in Fig. 6.

On the morning of February 20 the survey was extended to the northwest, finding only further seamounts that were not only unsuitable for anchoring but which raised the possibility of extensive acoustic shadowing for any location in that area. At 1400Z of February 20, the Gibbs proceeded due north to reach a continued rise that could be inferred from the soundings given on chart H. O. 0823, the only other bathymetric data of the area available to us. Except for one section at latitude 20°40' S, the entire track to 20°S showed a continued jagged bottom, and the rise predicted from the chart was not discovered. It was decided to return to the area of 20°40' S for anchoring and, after further survey (Fig. 7), the site of 20°41' S, 83°14' W was selected and the Gibbs was anchored there on February 22, 0315Z, in 2316 fathoms.

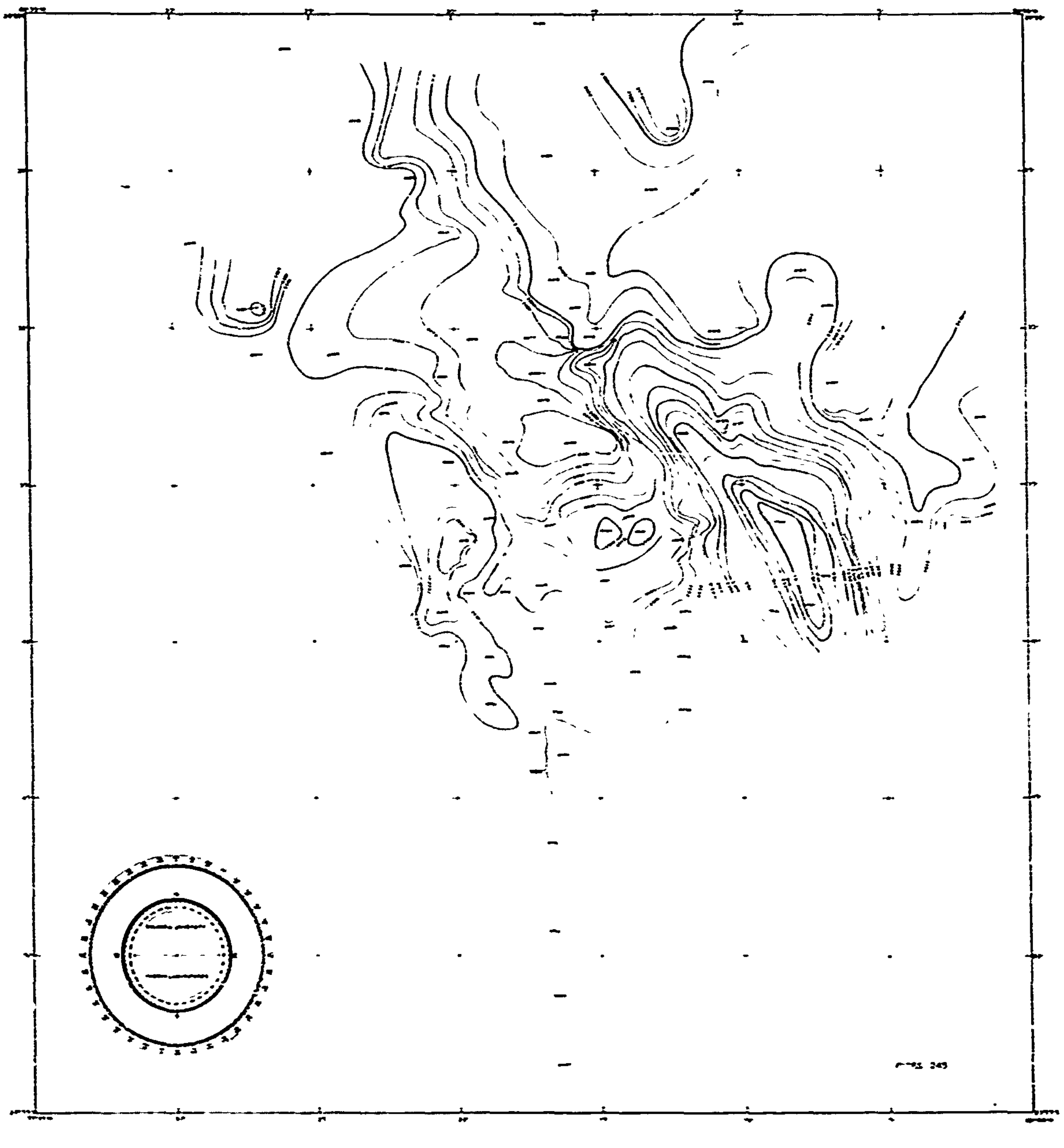

Fig. 7. Bathymetry of the GA site "B" where the USNS J. W. Gibbs established a hydrophone listening station. In the original report (Ref. :) the ship's track for the bathymetric survey is provided as an overlay.

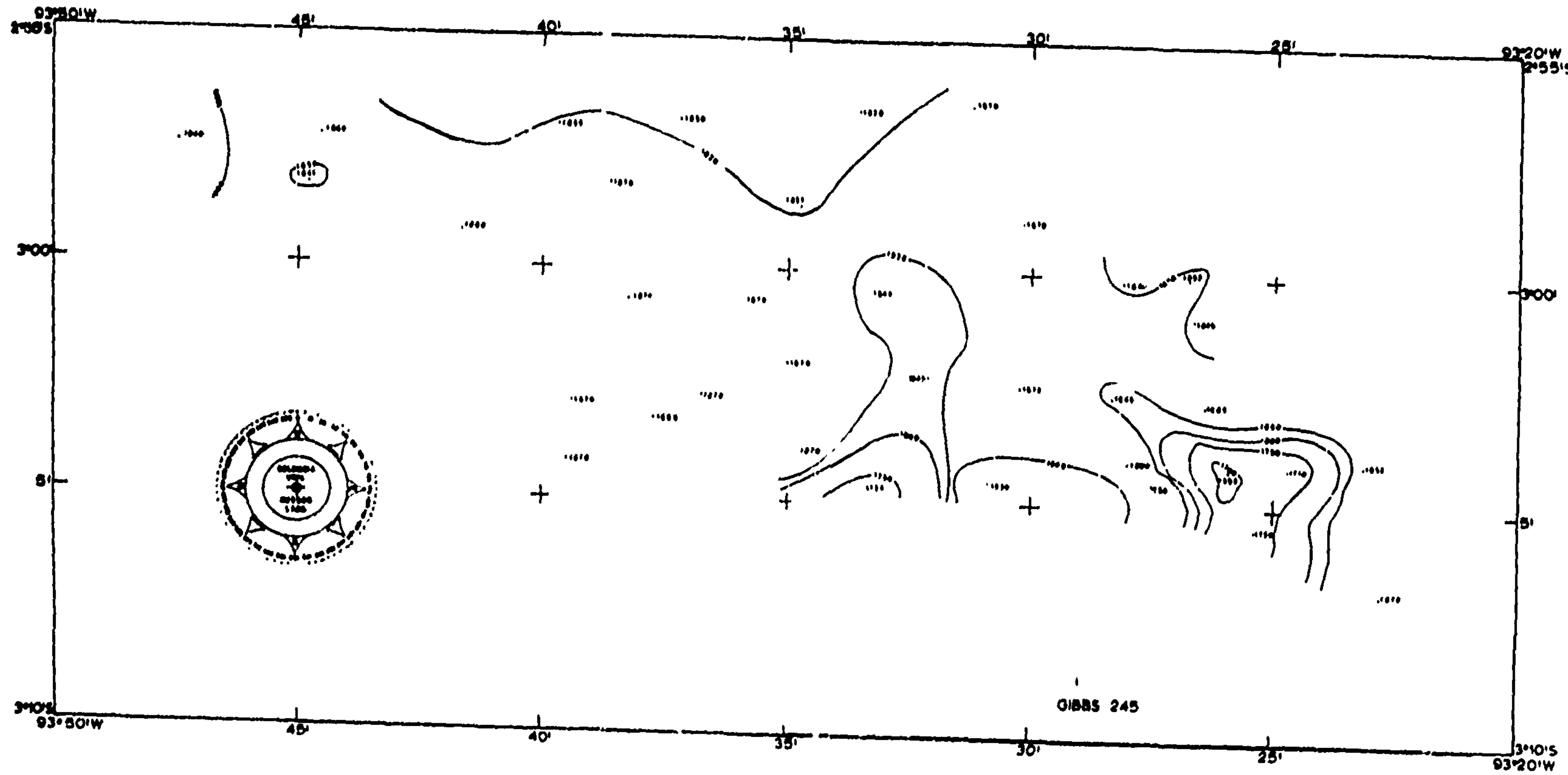

Fig. 8. Bathymetric survey carried out by USNS J. W. Gibbs prior to anchoring at listening station "A" during Project APTERYX. Ship's tracks for the survey are shown as an overlay in the original report (Ref. 1).

The fathometer records and partial surveys made by the Gibbs during APTERYX are of scientific interest in themselves because of the unexplored bathymetry of this ocean area. N. Cherkis of Hudson Laboratories compiled and analyzed these data which have been published as a separate report.[1] Figures 6, 7, and 8 are taken from this report and indicate the bottom bathymetry explored at both sites "B" and "A" during APTERYX.

B. Monitor at Station "B"

Monitoring hydrophones at "B" consisted of

1. a hydrophone close to the anchor in 2316 fathoms
2. a four-element vertical string suspended from the surface with hydrophones at 500, 1000, 2000, and 3000 ft
3. a single hydrophone suspended from the surface on light (Signal Corps) wire at a depth of 1700 ft.

Noise spectra taken on the first five of these hydrophones are shown in Fig. 9.

The four-element vertical string was floated off from the ship and suspended from a spar buoy. The hydrophone units contained individual preamplifiers modulating voltage-controlled oscillators to form a telemetry system so that the connecting cable could be kept light and flexible. After launching it was determined that the preamplifier gains had been set on the low side and the acoustical performance of the vertical string system was very nearly system-noise-limited at site "B." That is, any acoustic signal monitored by this listening system would have had to be greater in magnitude than the values given in the figures. However, the threshold by which the acoustic signal would have had to exceed the values for the system noise was

[1] N. Z. Cherkis, Bathymetric Report of Survey Operations in the Southeast Pacific Ocean, USNS J. W. Gibbs (T AGOR-1), Operation 245, 17 February - 16 March, 1967 (HL Tech. Rept. No. 143, October 1967).

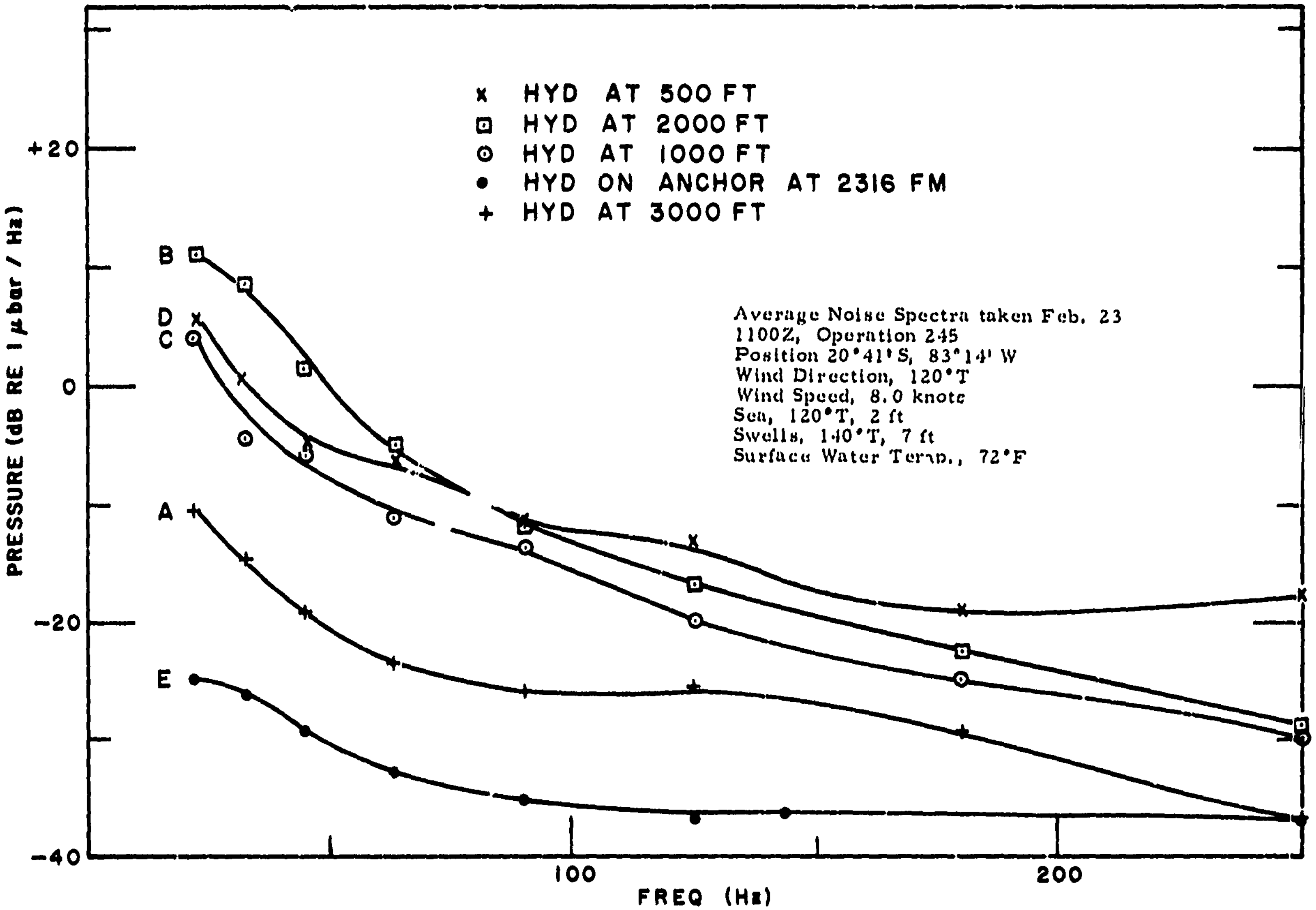

Fig. 9. Noise spectra for the hydrophones used at site "B." These data were obtained using instrumentation discussed in Section IV of this report. The excess noise of the hydrophones at the depths of 500, 1000, and 2000 ft is due to motion of the vertical hydrophone string excited by the sea surface. The 3000-ft unit is quieter because of the damping provided by a 50-lb weight, which tethered the bottom of the vertical string.

determined to be small, and did not exceed several dB for the 3000-ft unit. Evaluation of the noise spectra indicates that an explosive shot signal would have been positively monitored on the 3000-ft hydrophone element at site "B" if it had had a spectral energy corresponding to -50 to -60 dB re one erg/cm^2/Hz.

The single hydrophone on the bottom near the anchor was not subject to the system noise limitation of the vertical string, and, as Fig. 9 indicates, its noise spectrum was consistently low throughout the monitoring period. Evaluation from these data indicates that if the peak spectral components of the signals at or near 50 Hz had been as large as -80 dB re one erg/cm^2/Hz, they would have been positively monitored. This corresponds to an approximate transmission loss to the bottomed hydrophone of at least -130 dB, for Mark 61 PDC charges, and a greater loss with respect to larger charges.

An additional hydrophone suspended from the ship was used at site "B" but, and because of excitation by ship's motion through the suspension, its noise spectrum was at a considerably higher level than that of the units of the four-element vertical string.

No acoustic signals from either the New Zealand or Hawaiian areas were detected with these hydrophone systems at site "B." The following comments apply to this negative result:

1. Although the transmission paths to New Zealand from site "B" are somewhat shorter than those of site "A," it is clear from Fig. 2 that such paths must pass over a broader section of the East Pacific Rise.

2. The transmission paths to the Hawaiian area from site "B" are nearly 1000 miles greater than those for site "A." As the peak energy spectra for the monitoring at site "A" were of the order -55 to -65 dB re one erg/cm^2/Hz,

detection of the Hawaiian sources would not be expected in consideration of both the additional range and the noise levels of the suspended system at site "B."

3. Although gear for deep velocimetry casts was not available for use by the Gibbs in Project APTERYX, BT casts to 800 or 900 ft showed that the surface and upper layer water temperatures at site "B" were 3°C or more higher than had been expected on the basis of previously available data. This, and high salinity readings up to 37 mil percent, indicate that site "B" was well to the west of the Humboldt current or other currents that would provide cooling over the acoustic paths between New Zealand and site "B." In turn, the higher sound velocities in this area may imply greater bottom interaction and sound attenuation.

4. In view of the unknown and possibly complicated neighboring terrain indicated for site "B" by the initial survey, the existence of terrain shadowing by intervening seamounts cannot be ruled out as a contributor to the negative results of monitoring. Explosive charges used as sources by the Gibbs after raising anchor at site "B" were weakly detected by the New Zealand Table Lay array, but only for those shots directly exploded in the sound channel. Quantitative data for these shots and for comparison with subsequent data as the Gibbs moved from site "B" are not yet available.

Generally, the negative result at site "B" agrees with the preliminary conclusions indicated in the initial summary of this report, Section II.

C. Tow from Station "B" to Station "A"

In transit from site "B" to "A" the Gibbs acted as a source ship, towing a cw projector at 110 Hz with source level between 95 and 98 dB at a depth of 285 ft and also providing the following shot signals:

a. 16 2/3-lb Nitramon charges at 500 ft depth every two hours;

b. 15-lb Tetrytol charges in a depth sequence of 11 shots from 100 ft to 10,000 ft on a once-per-day basis.

All acoustic events from the Gibbs were carried out according to the plan of the Operational Order, Appendix A, except as follows:

a. At station "B" two "YO-YO" events, tests of the excitation of the cw signals as a function of depth of the projector in the thermocline, had been scheduled consisting of a cycling of the cw projector from the depth of 500 ft to the surface in 100-ft intervals. In attempting these events a series of cable and connector breakdowns were experienced. "YO-YO" events could not be held at site "B" but substitutions were made subsequently and satisfactory projector operation was maintained throughout the remainder of the experiment.

b. Because of poor monitoring of the 500-ft Nitramon shots reported by both New Zealand and Hawaii during the tow, 1000-ft shots were substituted for several days to improve the listening conditions. This substitution as well as the limited supply of materials for the explosive charges, i.e., fuse cord, suitable cont[illegible]s, weights, and the explosives themselves, resulted in a modification of the shot schedules of the Gibbs for the terminal two days of the tow on approaching site "A." The primary modifications were the elimination of the shallower shots in the Depth Shot Sequence (DSS) and the use of 10,000-ft charges in place of the 500-ft or 1000-ft charges sent every 2 hours.

D. <u>Location of Site "A" (3°04' S, 93°39' W)</u>

Prior to the operation, site "A" had been selected as a probable gentle rise of depth 1600 fathoms south of the Galapagos Islands at location

2°30' S, 90°00' W. Unlike the bottom at site "B," the bottom observed during the approach to and in the area of site "A" was essentially smootn although a few sharp rises of height 300 to 500 fathoms above the bottom were observed.

At site "A," however, we had the advantage that reliable communications could be obtained with the Operations Coordinator for a 4-hour contact interval every evening. Also, the preceding tow of the Gibbs had acted as a rough acoustical survey of the transmission paths to both the Hawaiian and New Zealand monitoring areas. The coordinator was able to inform the Gibbs that acoustic reception from the designated site "A" was markedly inferior to that observed from both the projector cw signal and the shot sequences during the prior 3-day interval. Accordingly, during the period March 9 to the morning of March 11, the Gibbs was able to seek a more optimum site "A" and did this by steering west by southwest toward a position lying on a great circle path between FLIP and the position of the Gibbs on the dates of March 7-8. This also shortened the range to the Hawaiian area by some 250 miles over the relatively shallow East Pacific Rise (Fig. 2).

The cost of this maneuver to the west was the probability of increased terrain blockage by the eastern tip of the Tuamotu Archipelago (Ducie Island) to the New Zealand area. Nonetheless, the superiority and reliability of acoustic reception to the Hawaiian area that was indicated by the monitor reports during the Gibbs tow together with the negative result of the monitoring at site "B" forced us to make this decision so as to obtain optimum monitoring at site "A." The Gibbs anchored at site "A" on March 11, 1400Z, in 1880 fathoms, and monitor reports from a depth shot sequence held prior to anchoring indicated that this site was well chosen with respect to Hawaii.

The brief survey made prior to anchoring at site "A" is shown in Fig. 8. Prior to anchoring it was appreciated that there was a strong westward current acting during the survey maneuvers. After anchoring, this current was estimated by a floated chip method and found to be consistently of the order of two knots at this location. There was strong evidence, however, that this was only a surface current and that there also existed a subsurface current flowing to the east. This showed itself both in the set of the cables of the surface suspended vertical units and also in the set of the cable for the BT apparatus.

E. Monitor at Station "A"

With the hindsight of our experiences at site "B," two major improvements were incorporated into the design of the listening hydrophone systems at site "A." These were:

1. Additional preamplifiers were incorporated into the hydrophones used in the vertical suspended string, increasing the signal level by 30 dB with respect to the system noise level measured at site "B."

2. The surface suspension of the vertical string was improved by the use of the following techniques:

a. The tethering cable to the anchored ship was terminated in a light surface buoy with large above surface area to act as a sail and to assist in maintaining the vertical string to leeward of the ship. In this way we minimized some of the "wrap-around" problems encountered at site "B" and in previous operations using vertical suspensions.

b. The tie point for the tether consisted of a subsurface mass partially isolated from surface excitation by shock cord.

c. Connection to the top of the vertical string was made through a catenary which primarily used the cable weight itself with some lumped loading. This cable was 1000 ft long and designed so that from the tie point of (b), above, the bottom of the catenary was at a depth of 500 to 600 ft and the end tied to the top of the vertical string was at a nominal depth of 300 ft. We were able to design and launch this system thanks to the careful calibration of the buoyancy or water weight of all elements of the system by E. T. O'Neill as part of his painstaking and conscientious preparations prior to APTERYX.

d. Damping shields, termed "rat-guards," were used along the subsurface catenary and in several of the small catenaries of the tether to the ship, i. e., between the surface floats. These were designed originally to minimize coupling to the ship as the ship swung on its anchor; in practice, they further maintained the orientation of the vertical string with respect to the ship in the strong surface currents encountered at site "A."

Noise spectra taken on this system after launching are shown in Fig. 10. The hydrophone depths are those of the original vertical string at depths of 500, 1000, 2000, and 3000 ft plus the additional 300 ft of depth introduced by the catenary suspension. The system was considerably quieter than the system of site "B." During March 13 an intermittent contact developed in the telemeter cable from the vertical string, disabling the 800 and 2300 ft units. It is clear from Fig. 10 that the 1300-ft unit suffered from considerably greater noise than did the 3300-ft unit, and the latter therefore became the primary monitor hydrophone during the remaining period at site "A."

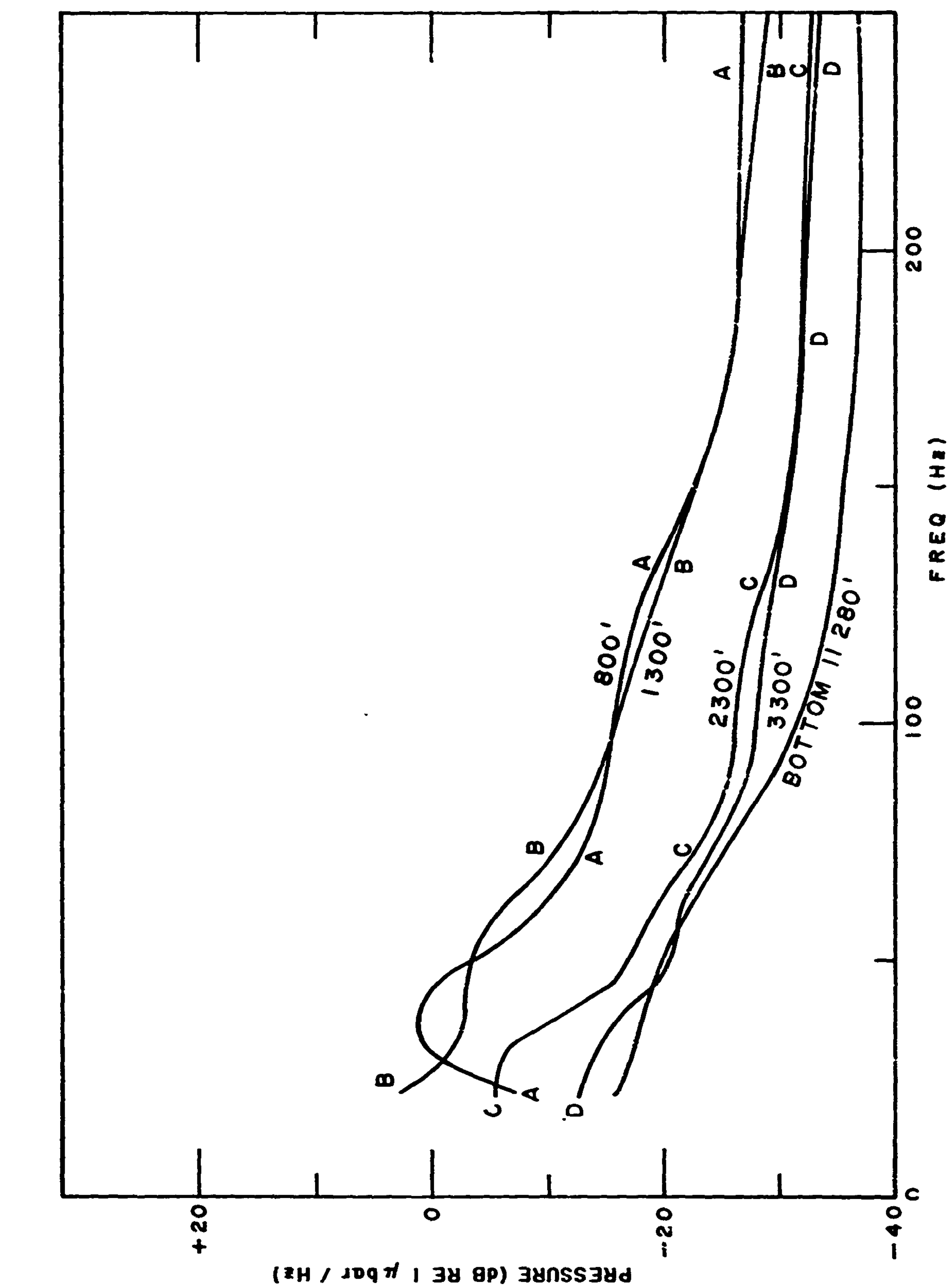

Fig. 10. Noise spectra taken on the hydrophone units at site "A" during Project APTERYX. The 800- and 1300-ft units are noisier than the deeper units due to excitation by the tethering system.

The bottomed hydrophone off anchor at site "A" performed well and data on its noise spectra are also shown in Fig. 10. Again, however, no long-range acoustic signals were detected on this unit at depth 1880 fathoms at the location shown in Fig. 8.

During the entire station at site "A" the sea state was never more than one and often was zero. The 2-knot current, however, raised special problems - indeed, the working of the double-armored cable at the 300-ft depth of the subsurface float supporting the vertical string must have been considerable, for on March 15, 2230Z, the cable severed at this point.

F. Acoustic Reception at Station "A"

Data were obtained on sections of four acoustic serials at station "A":

1. most of the 800-ft shots from Hawaii during serial HW-1, including two AD/DSS sequences; also, some twelve 60-ft shots were identified that lay mostly in the range interval from 1100 to 1250 miles from the start of HW-1. Reception of these shallow events is most probably due to colder local water temperatures in that area.

2. the initial 800-ft shots of the serial HW-2 including the first AD/DSS to a range of about 350 miles from the starting point of the serial.

3. the larger shots of the serials NZ-2 and NZ-3 including a Depth Shot Sequence based on 15-lb TNT charges.

IV. INSTRUMENTATION

The hydrophones deployed by the Gibbs during APTERYX consisted of a bottomed hydrophone and a four-element vertical string with hydrophones at depths of 500, 1000, 2000, and 3000 ft from a buoyant float at the top of the

string. At site "A" this was floated from the ship by means of a long, mass-loaded catenary cable so that the top buoyant element was in equilibrium position at a depth of 300 ft below the sea surface. The Gibbs was anchored, and surface currents acting on the subsurface float provided drag to obtain a horizontal separation of the string from the ship of the order of 1000 yards.

The connecting cable consisted of one-quarter inch o.d. armored BT cable. The individual hydrophones were mounted with battery-operated preamplifiers and voltage-controlled oscillators (VCO's) contained in pressurized cans. The VCO's were connected in parallel to the vertical string. The telemetered signals were detected by filters and discriminators on shipboard. This system (shown in Fig. 11) was later improved and expanded as the basis for the Hudson Laboratories 20-element vertical array.

Each signal was amplified and frequency-band-limited by the use of a set of one-half octave bandpass filters. The center frequencies and the effective pass bands of the filters are listed in Table I. The signals were then squared by a solid state circuit with response time much faster than the highest frequencies of the signals and the resultant energy was integrated by a conventional circuit employing chopper-amplifier solid state components. The signals were adjusted by preamplifiers to fall within the dynamic range of the squaring circuit and integrator, which was at least 30 dB. A bias control could be used to cancel the average energy of the sea noise background so that the integrator output, displayed on an eight-channel graphic recorder, would register a shot arrival as a distinct step in the output level. The system was also used to measure average noise powers by setting the bias at zero and measuring the energy increment for a fixed period of time such as 30 sec.

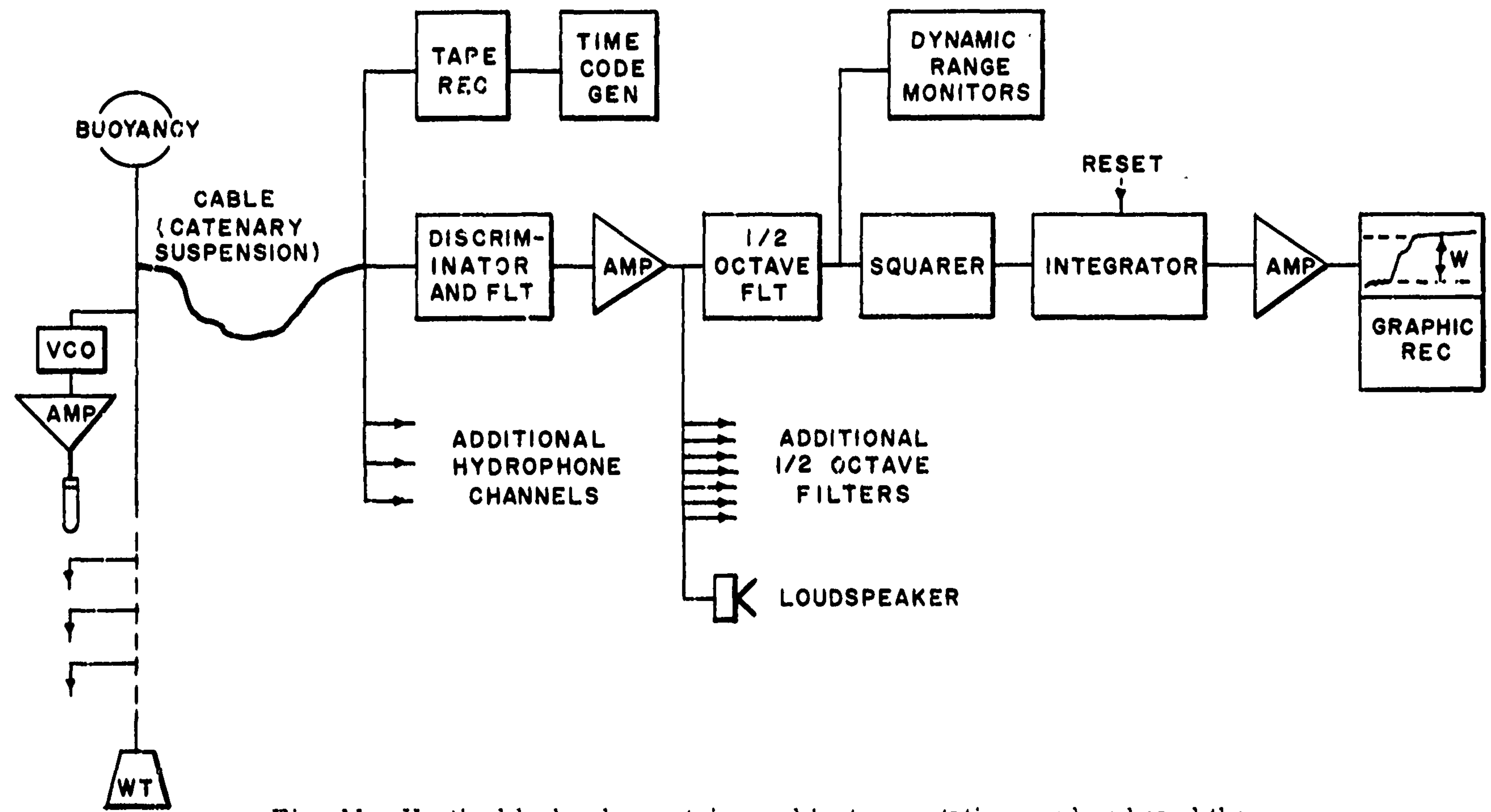

Fig. 11. Vertical hydrophone string and instrumentation used on board the USNS J. W. Gibbs during Project APTERYX. Data reduction is obtained as the energy increment of an explosive shot detection after pass-band limiting by a set of eight one-half-octave filters.

Table I.

Band Pass and Center Frequencies (in Hertz)

for Half-Octave Filters Used in APTERYX.

Lower Freq. f_L	Center Freq. f_C	Upper Freq. f_U	Bandwidth $f_U - f_L$
16.7	22	27.3	10.6
24.3	32	39.7	13.4
34.0	45	56.0	22.0
47.1	63	79.1	32.0
68.5	90	111.5	43.0
93.2	125	156.3	63.1
134.7	180	225.3	90.6
189.1	250	310.9	121.8

These instruments worked well and had a measurement accuracy that was better than 1.0 dB, which is also the calibration accuracy of the overall system, including the hydrophones. It was characteristic of the suspended hydrophone system that occasional surges were noted, especially in the low-frequency pass bands, and these made it difficult to set the bias control for noise compensation. However, the comparative display on the graphic recorder of all eight pass bands made it possible to isolate the step due to the energy of the shot arrival in contrast to the more erratic jumps that originated in hydrophone motion. It was feasible to use the instrument for real time analysis when the signals represented a continuing series of acoustic events of the same type; otherwise, playbacks of the tape recorder

were used so that amplifier gains and bias level settings could be optimally adjusted for the dynamic range of the signals in each of the parallel-recorded pass bands.

Acoustic energy levels were obtained by reading the energy displacements on the graphic recorder, by calibration of the fixed gains of the system, and by recording the variable gains used to adjust each signal for an optimum integrator output. Further, the resultant levels were divided by the frequency bandwidth of the respective one-half octave filters to obtain the average energy level per Hertz for each filter. In the graphical plots that express these data, the levels were plotted at the center frequencies of the bandpass filters, and these points were connected by lines to show trends clearly.

The data curves, presented in the next section, frequently show kinks and irregularities that are greater than the 1.0-dB measurement accuracy of the instrumentation. Some of these, necessarily, originate in reading errors that occurred when the signals were very weak and could not be easily discriminated from the noise background. The majority of these kinks, however, are real and occur because the input energy spectrum of the explosive sources is highly modulated within the bandwidth of the filters, especially those with the higher center frequencies. This is discussed and illustrated in Appendix B which deals with the energy spectra of the explosive sources. As a result, the linear averaging of the energy across the one-half octave filter bandwidths is inadequate and is the major cause of the irregularities found in the data spectra.

It may be noted that subsequent to Project APTERYX Hudson Laboratories converted the data acquisition and processing procedures used

in its acoustical experiments to fully digitized systems and computer-processed data reduction. These permit far more detailed spectral compensation for the variations of source level, and not only provide better data but also enable more precise analyses to be made of the spectra to determine, for example, the frequency dependence of the absorption and attenuation processes that affect the propagation. However, it was not possible to apply these techniques to the APTERYX data; also, the more accurate data would have not changed the conclusions of this report.

V. DETECTED SIGNAL LEVELS

The shot signals monitored during APTERYX were analyzed by the methods discussed in the previous section, and are presented here in graphic form. The plots show the energy increment due to the shot arrival averaged over the effective pass band of the one-half octave filter as a function of the center frequencies of the analyzing filters. The filter parameters are given in Table I. Note, for example, that a datum point at 250 Hz represents an effective pass band that extends from 189 to 311 Hz.

The signals that were detected were weak and were difficult to discriminate from the noise background. Further, the vertical suspension system in the sound channel produced occasional "surges" due to surface coupled motion to the hydrophones, and this made it additionally difficult to detect weak arrivals. Some relief was provided by strongly attenuating the frequencies below 30 Hz, although this effectively eliminated the analysis band centered at 22 Hz. On occasion, and for the stronger arrivals, we

were able to remove the input filter and make measurements in the 22-Hz band; invariably, these signal levels were much weaker than those in the higher frequency bands, presumably due to normal mode effects. For these reasons, the 22-Hz data have not been included in this report. Also, a nominal correction factor had to be included to compensate for the effect of the 30-Hz roll-off, and this makes the data of the 32-Hz pass band less reliable that that of the higher frequency bands.

Some additional shots were detected that are not reported here; that is, we have removed data if the signals were too weak to be measured accurately, if the signal identifications were uncertain, or if the calibration data were considered unreliable.

In some of the figures of this section, giving the shot spectra, it was necessary to displace individual curves by fixed dB increments with reference to the signal level scale so as to avoid overlapping of the curves. Such curves are lab. by giving the offset value in dB, i.e., -10 dB, with the understanding that the value in parentheses is to be added to the scale reading of the ordinate.

Figs. 12 through 25.

Spectra of signals detected by the 3300-ft depth hydrophone at site "A" during Project APTERYX. Ranges given in the figures are from the hydrophone to the position of the explosive shot. Figures 16, 17, 18, and 19 are averages that summarize a small section of the data from Fig. 15. Likewise, Fig. 21 summarizes data from Fig. 20, and Fig. 22-A summarizes data from Fig. 22.

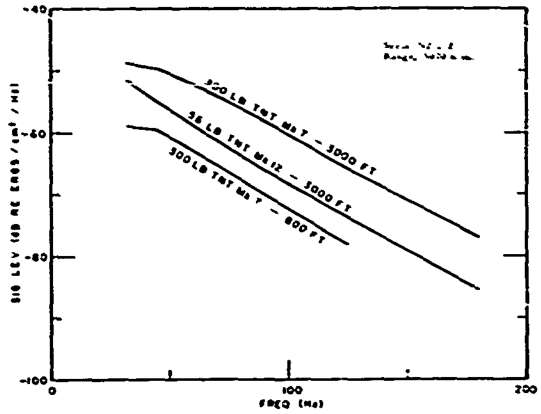

Fig. 12.

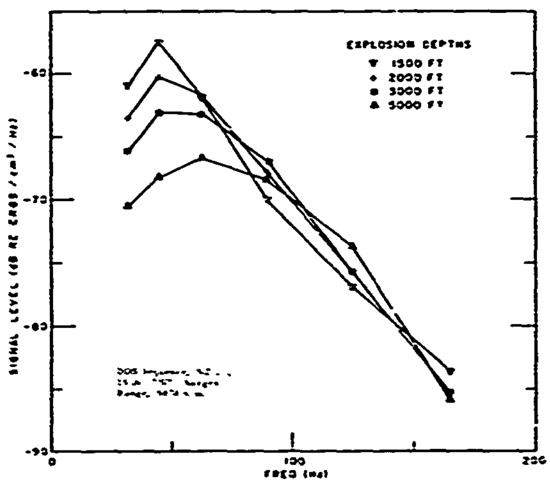

Fig. 13.

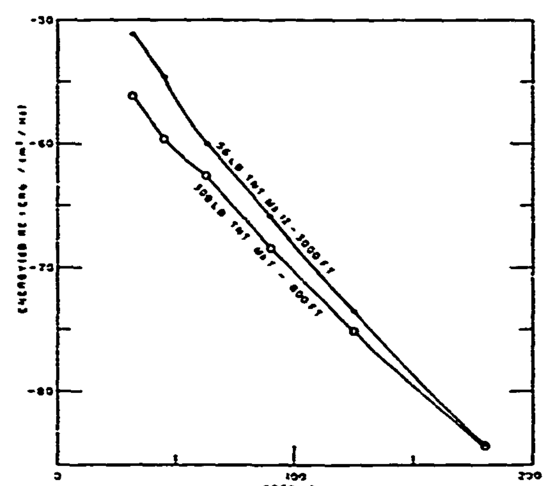

Fig. 14.

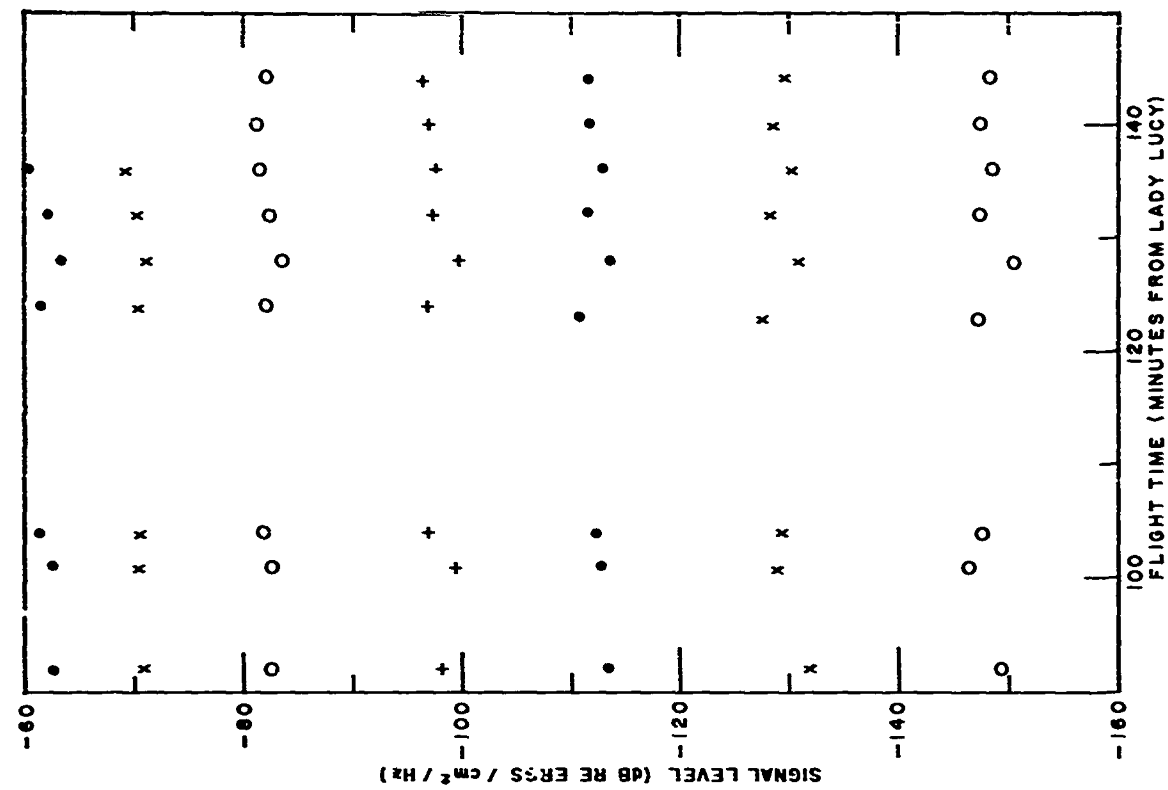

Fig. 15B.

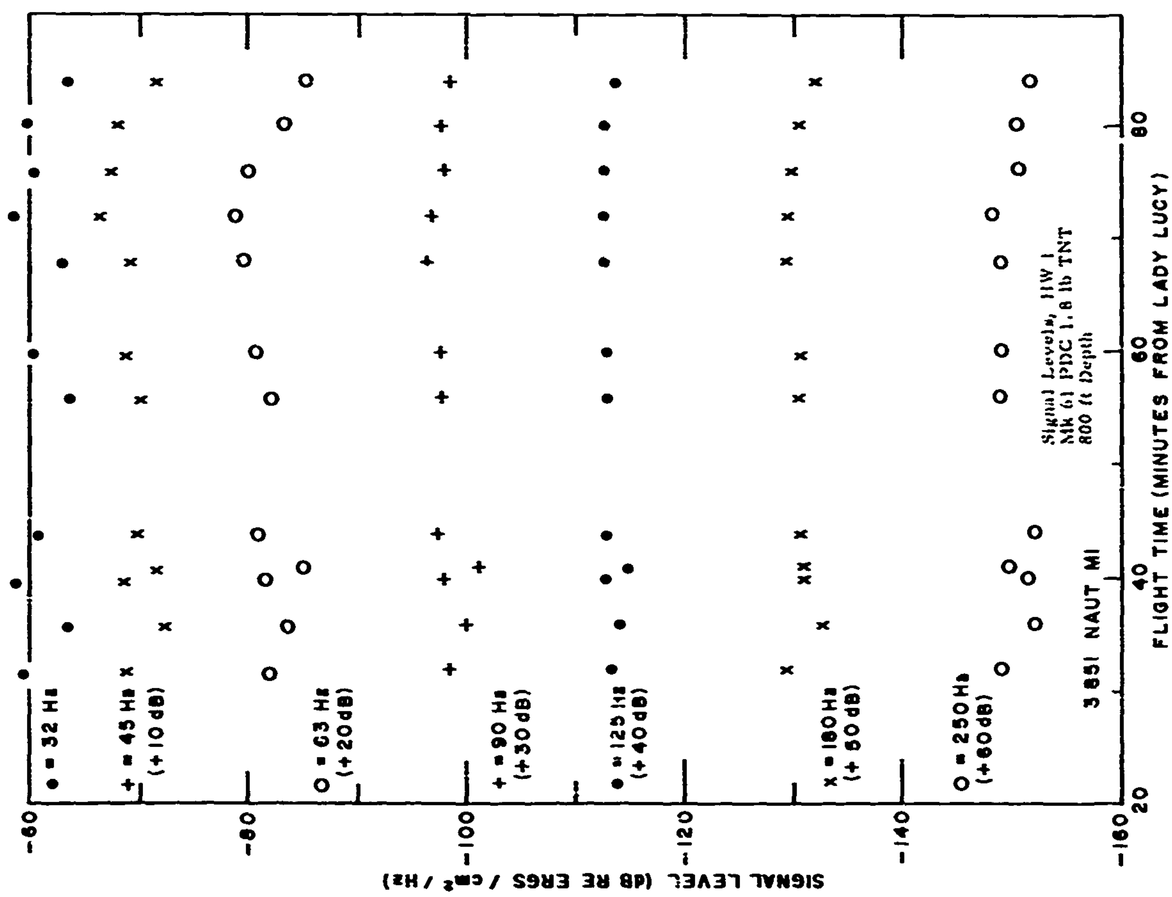

Fig. 15A.

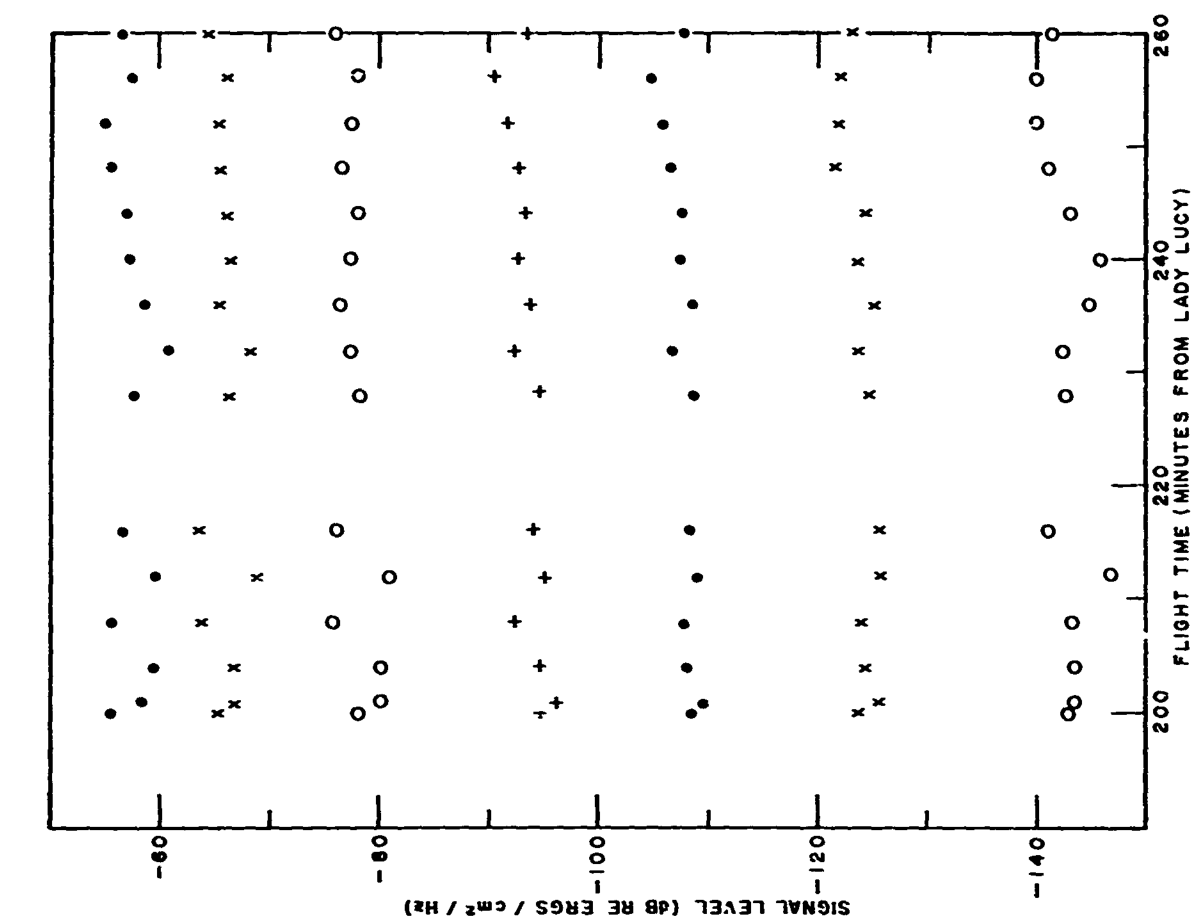

Fig. 15D.

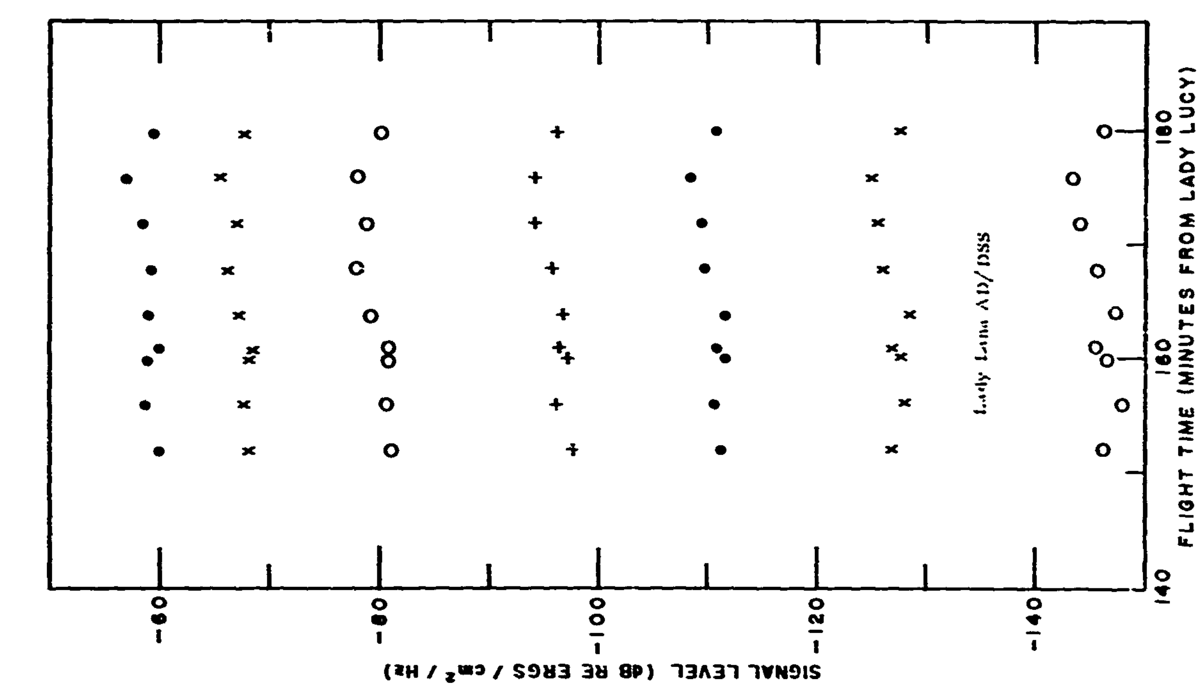

Fig. 15C.

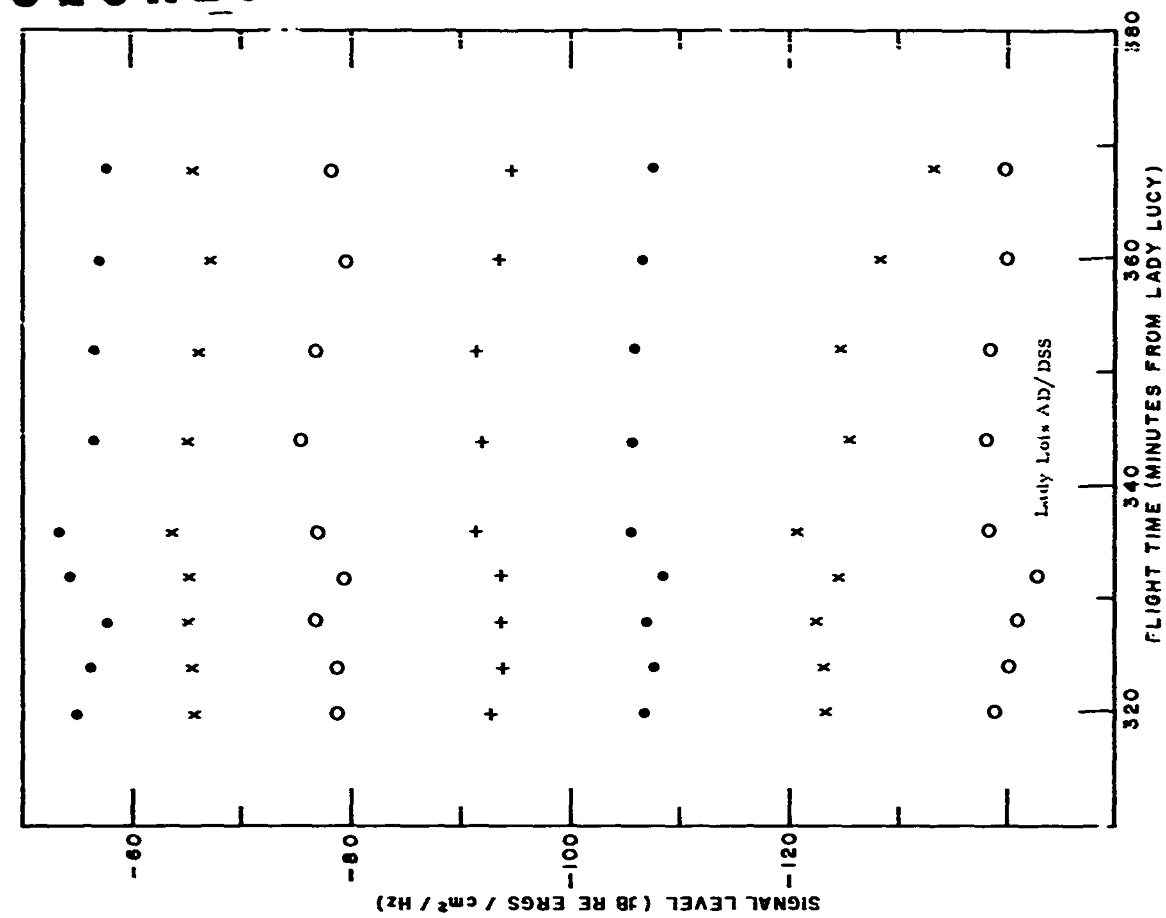

Fig. 15F.

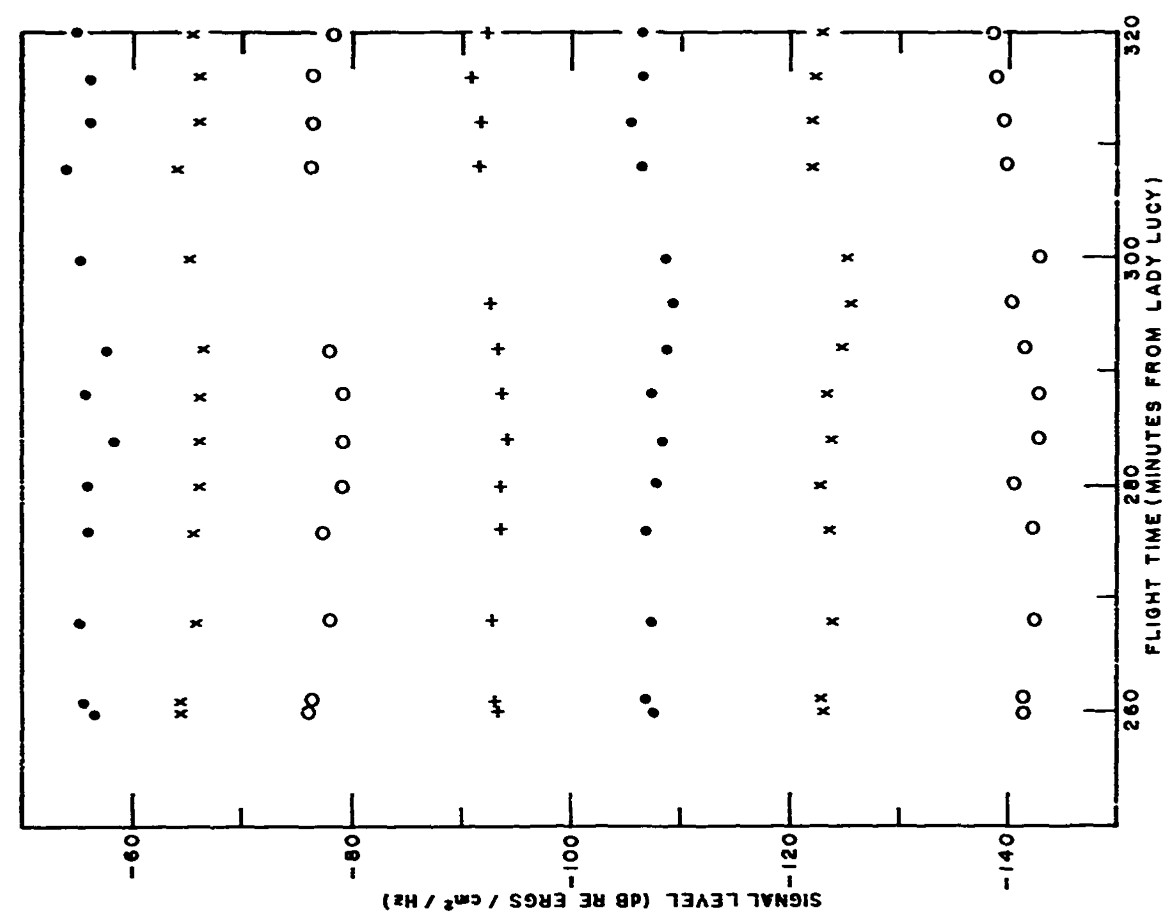

Fig. 15E.

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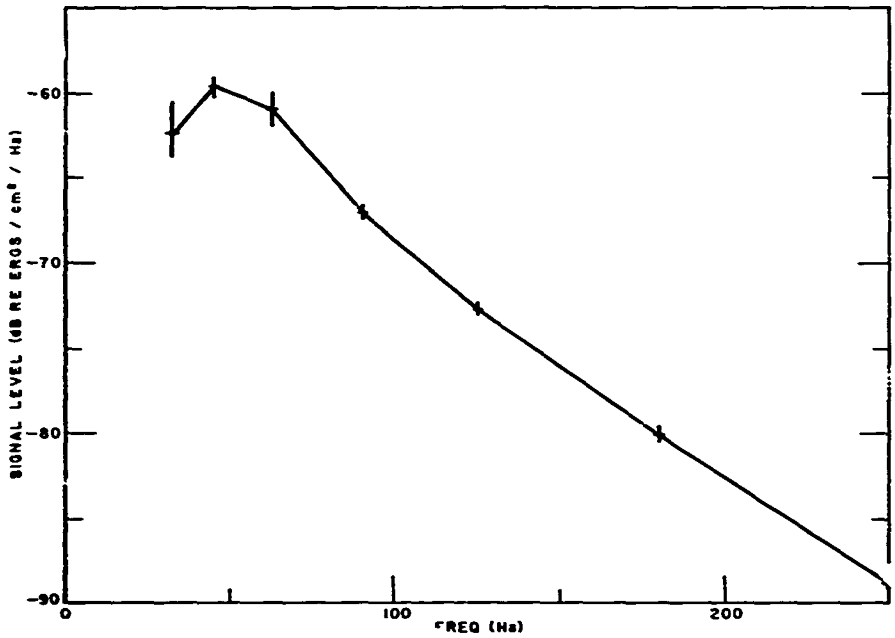

Fig. 16. Average signal levels, HW 1, Mk 61 PDC 1.8 lb TNT, 800 ft depth, average range 3700 n.m.

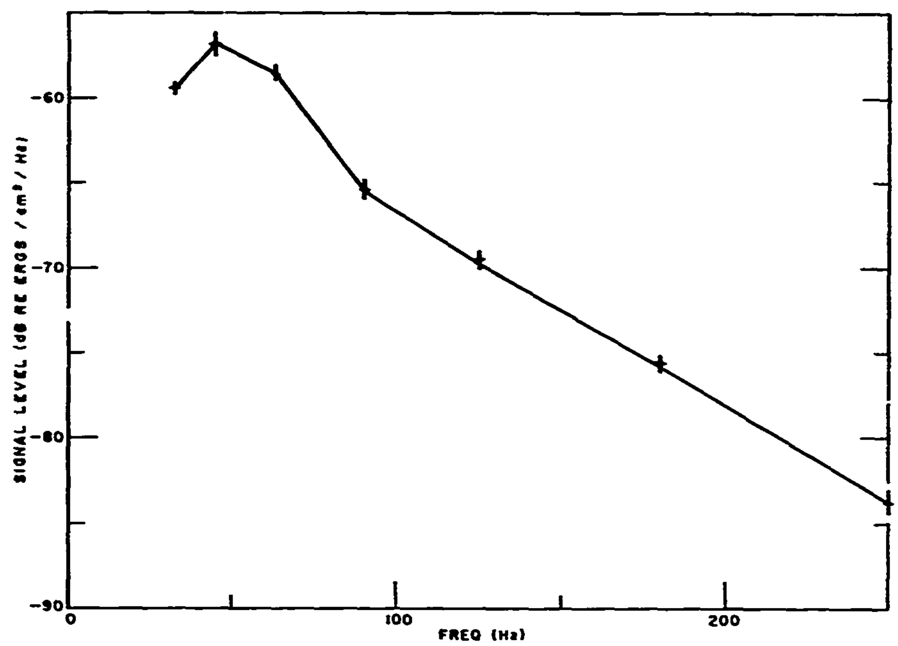

Fig. 17. Average signal levels, HW 1, Mk 61 PDC 1.8 lb TNT, 800 ft depth, average range 3310 n.m.

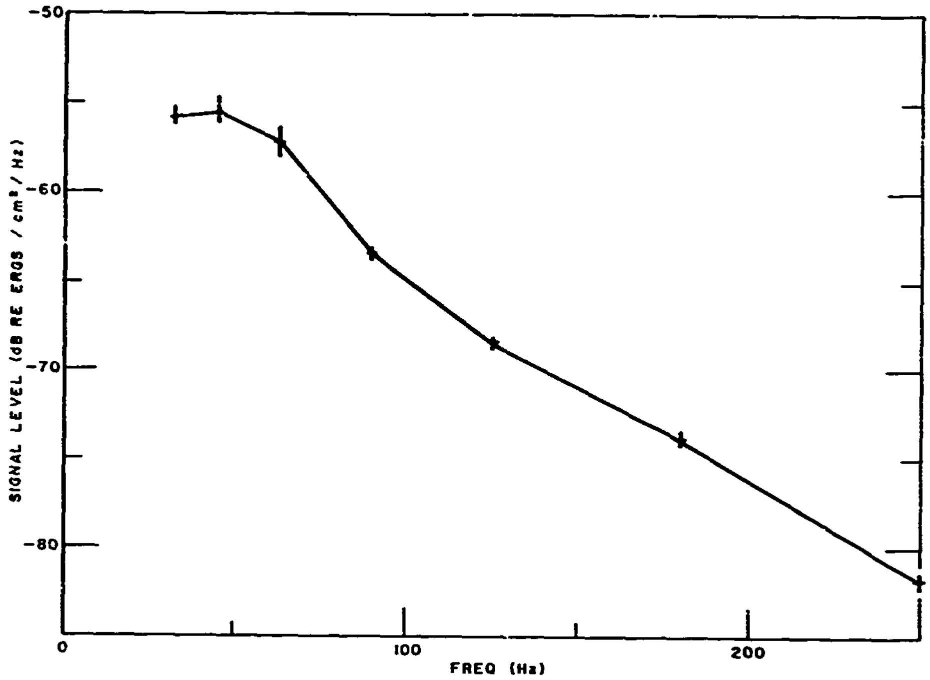

Fig. 18. Average signal levels, HW 1, Mk 61 PDC 1.8 lb TNT, 800 ft depth, average range 3020 n.m.

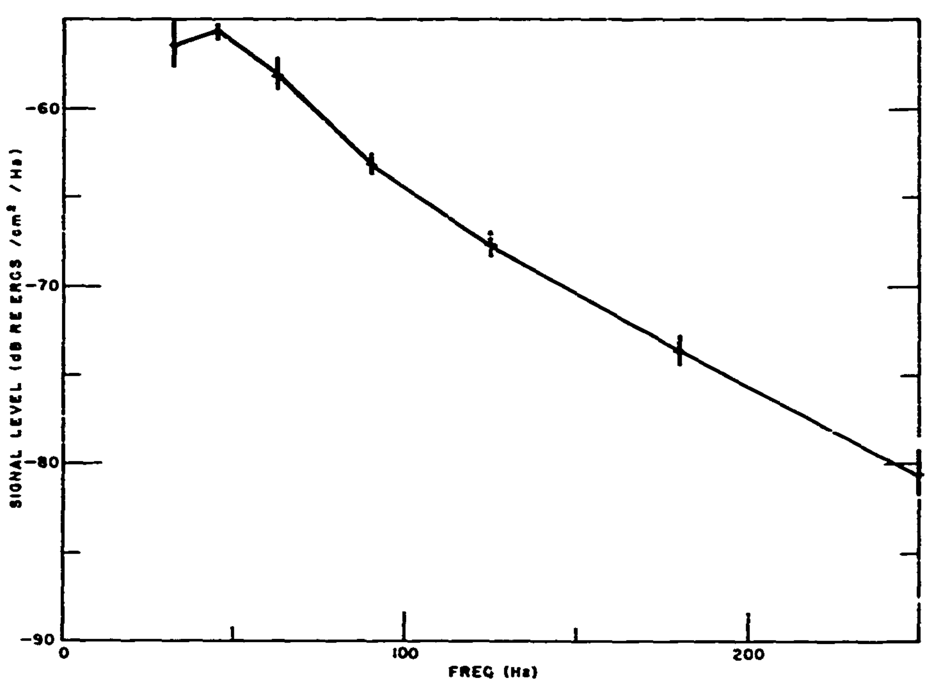

Fig. 19. Average signal levels, HW 1, Mk 61 PDC 1.8 lb TNT, 800 ft depth, average range 2680 n.m.

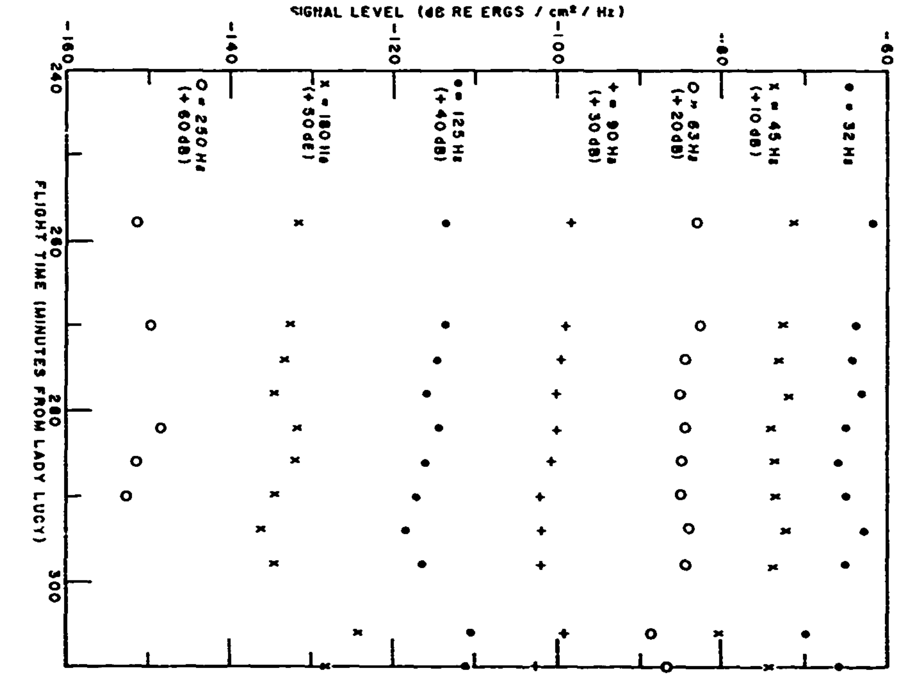

Fig. 20A. HW 1, Mk 61 PDC 1.8 lb TNT, 60 ft depth.

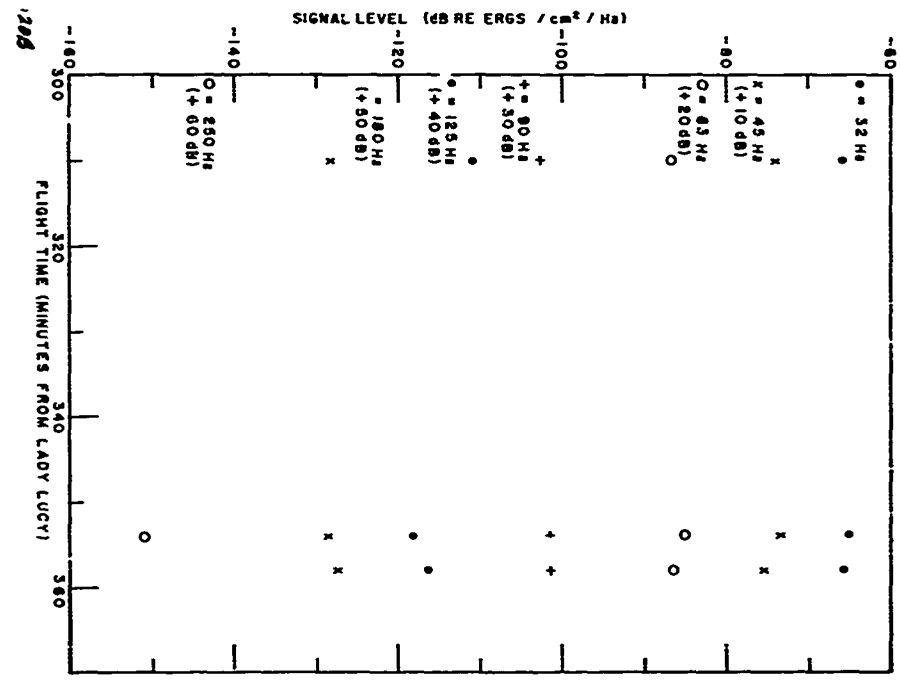

Fig. 20B. HW 1, Mk 61 PDC 1.8 lb TNT, 60 ft depth.

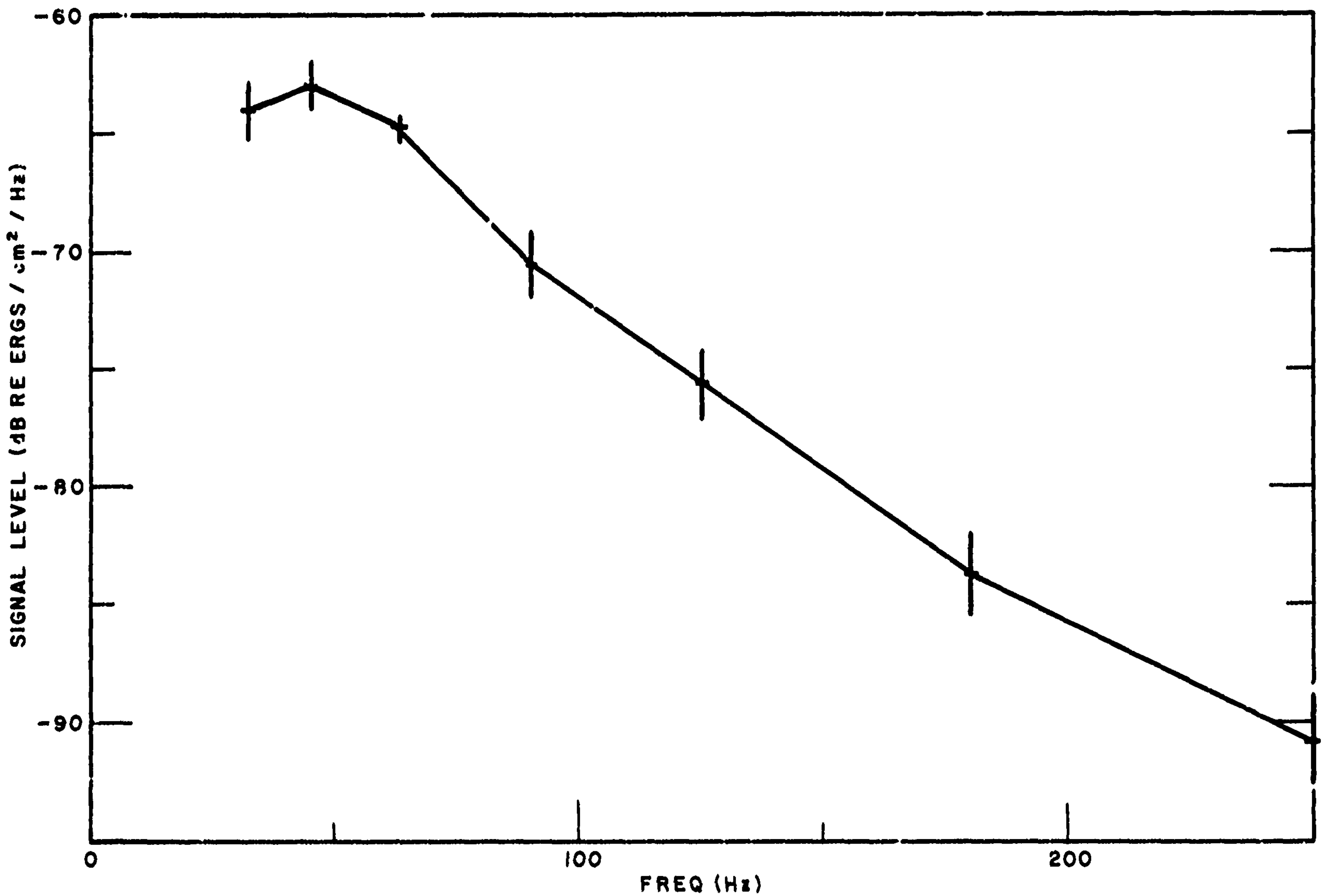

Fig. 21. Average signal levels, HW 1, Mk 61 PDC 1.8 lb TNT, 60 ft depth, average range 2940 n.m.

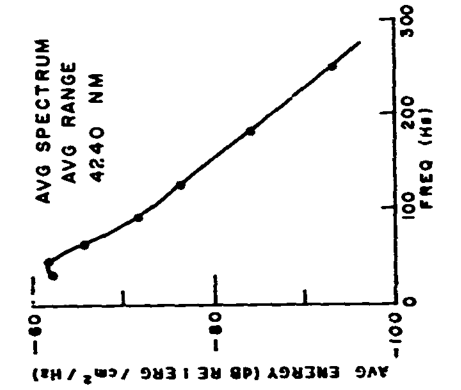

Fig. 22A.

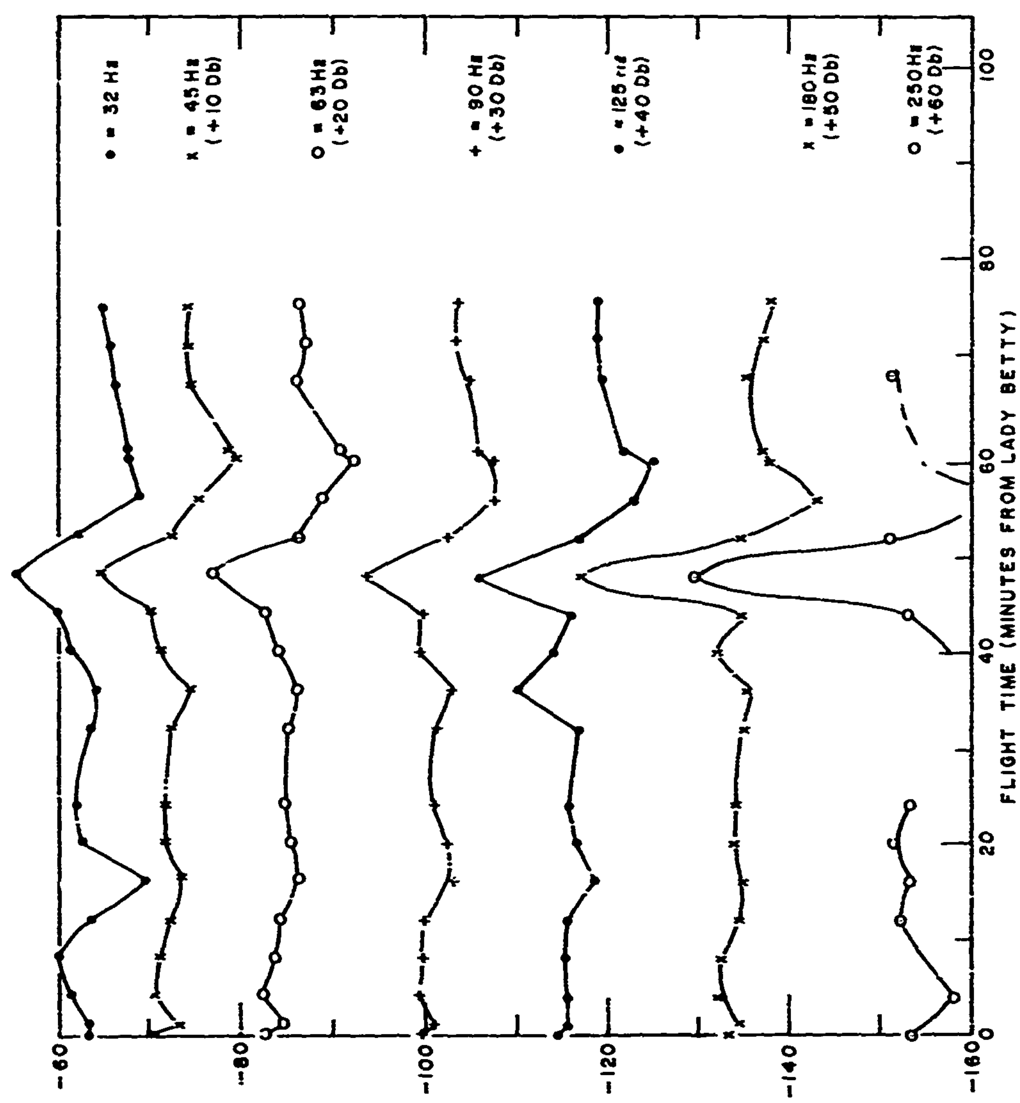

Fig. 22. Shot energy spectra for 800 ft Mk 61 PDC, HW 2A, 16 March 1967.

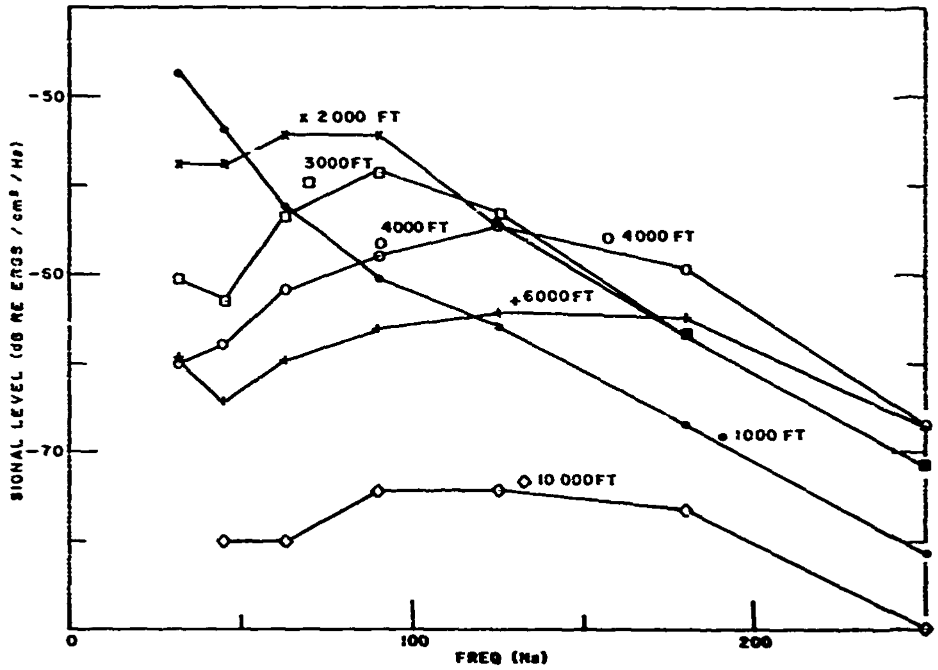

Fig. 23. HW 1A, Lady Lois DSS, range 2501.7 n.m., Mk 59, 4 lb TNT.

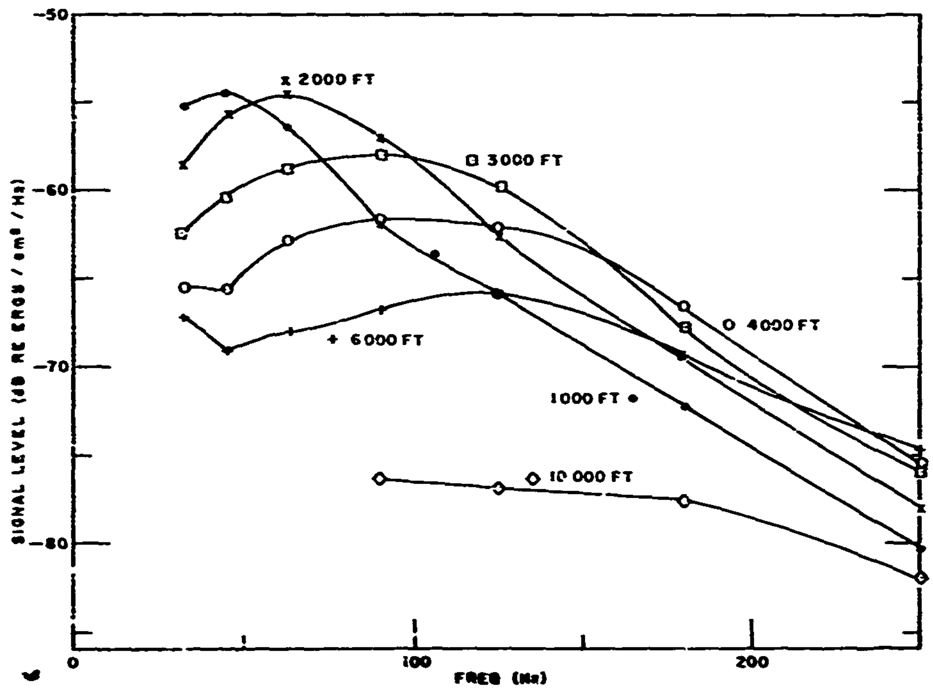

Fig. 24. HW 1A, Lady Lana DSS, range 3264.1 n.m., Mk 59, 4 lb TNT.

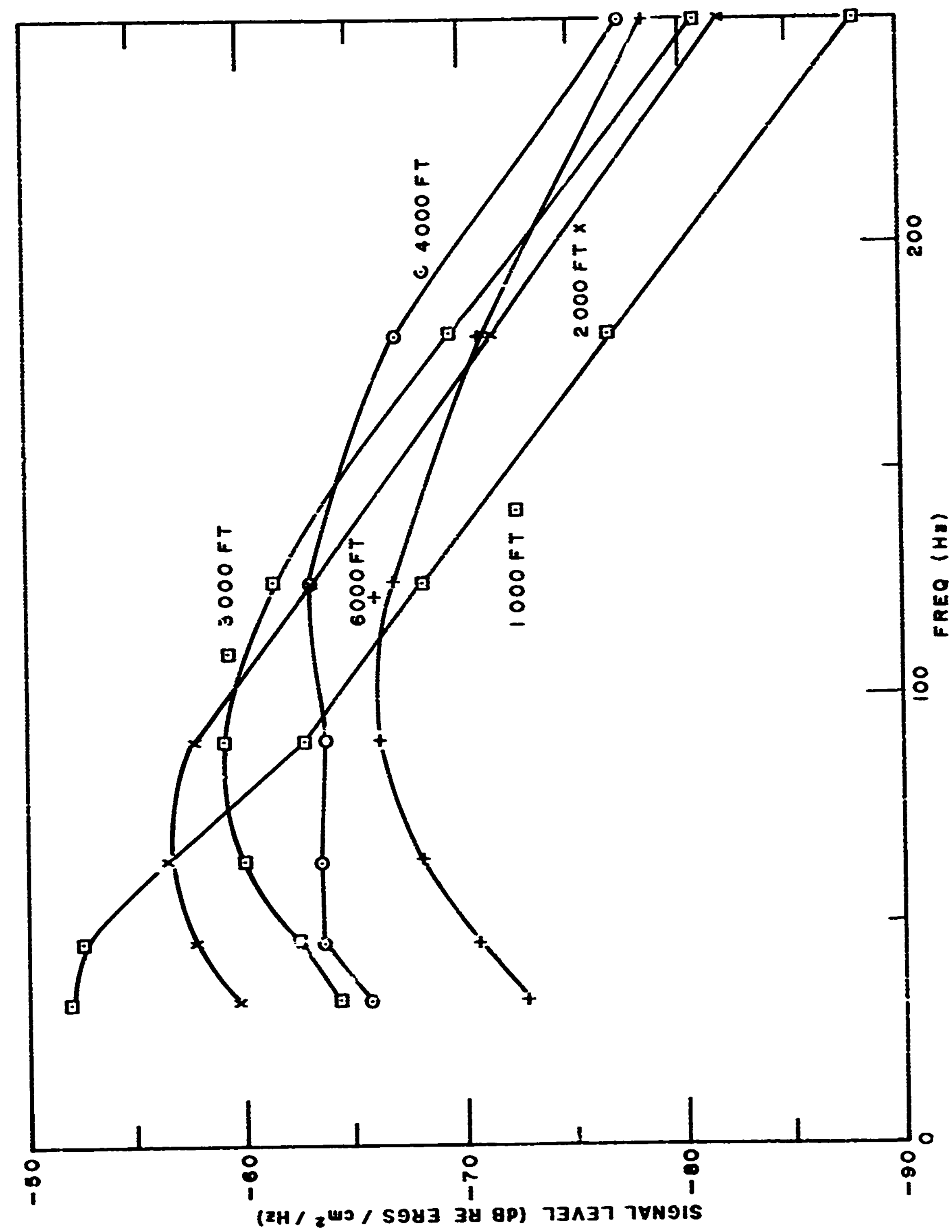

Fig. 25. HW 2A, Lady Betty DSS, range 419.6 n.m., Mk 59, 4 lb TNT.

VI. TRANSMISSION LOSS DATA

We did not have specific calibration data for the source spectra of the explosive shots used in APTERYX. Accordingly, these were calculated from scaling law theory and the results are given in Appendix B. Figure B2 compares a computed spectrum of a 1-lb TNT shot with that measured in a subsequent experiment; it is apparent that the scaling law calculations cannot be taken as reliable spectra, especially when analyzed using filters with a bandwidth that is narrower than or comparable to the bubble pulse frequency of the shot. Also, the low-frequency components of the spectrum increase with frequency more rapidly than $(\text{frequency})^2$; thus, the low-frequency extrapolation of the spectra of Appendix B can be expected to be too large in view of the 6-dB/octave increment assumed for the shots in going from low frequencies to the first spectral maximum.

However, if the source spectra are accepted as having the correct average magnitude over the given filter passbands of Table I, the signal spectra of Section V can be normalized with respect to the variations in depth and weight of the source charges to give a transmission loss spectrum. This is defined as

$$\overline{(\text{Trans. Loss})} = \overline{(\text{Signal Level})} - \overline{(\text{Source Level})} \qquad (1)$$

where the bars over the quantities emphasize averaging over a given frequency passband and the values are quoted for the nominal center frequencies of each passband. In (1), all values are expressed in dB.

The transmission loss spectra are given in Figs. 26 through 38. If these curves are compared with the original signal level data of Figs. 12

Figs. 26 through 38.

The transmission loss spectra for the shot sources used in Project APTERYX. These data combine the signal level spectra of Section V with the source level spectra calculated in Appendix B. Figures 29 through 34 summarize data from the HW-1 and HW-2A serials as an average over a limited section of these tracks, and apply to the data of Figs. 16 through 19. and Figs. 21 and 22. Some curves have been offset to avoid confusion. The values given in parentheses for these curves are to be added to the ordinate values.

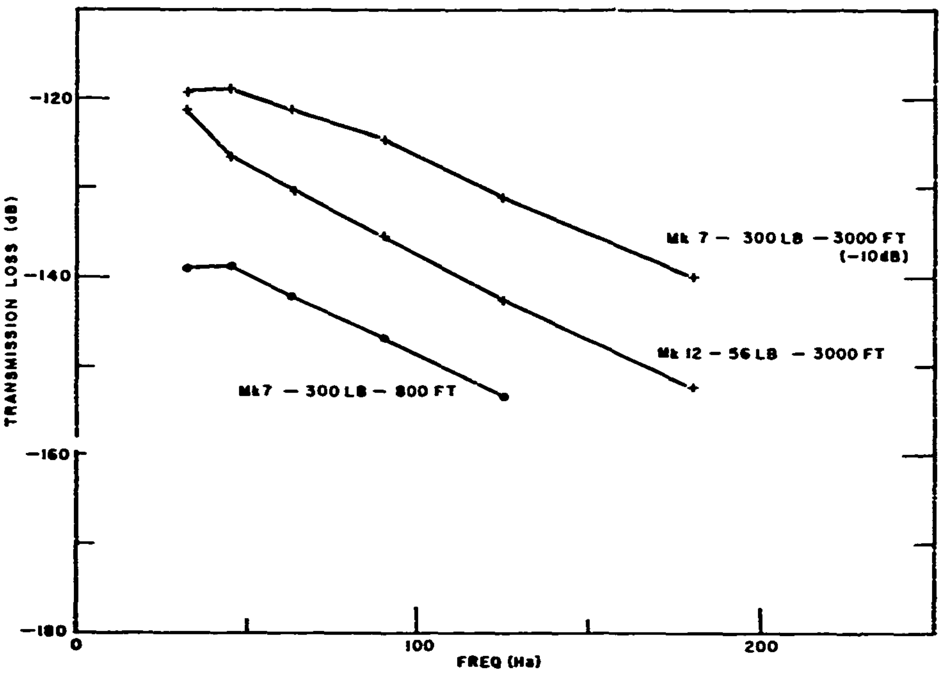

Fig. 26. Transmission loss, NZ 2/1, range 5070 n.m.

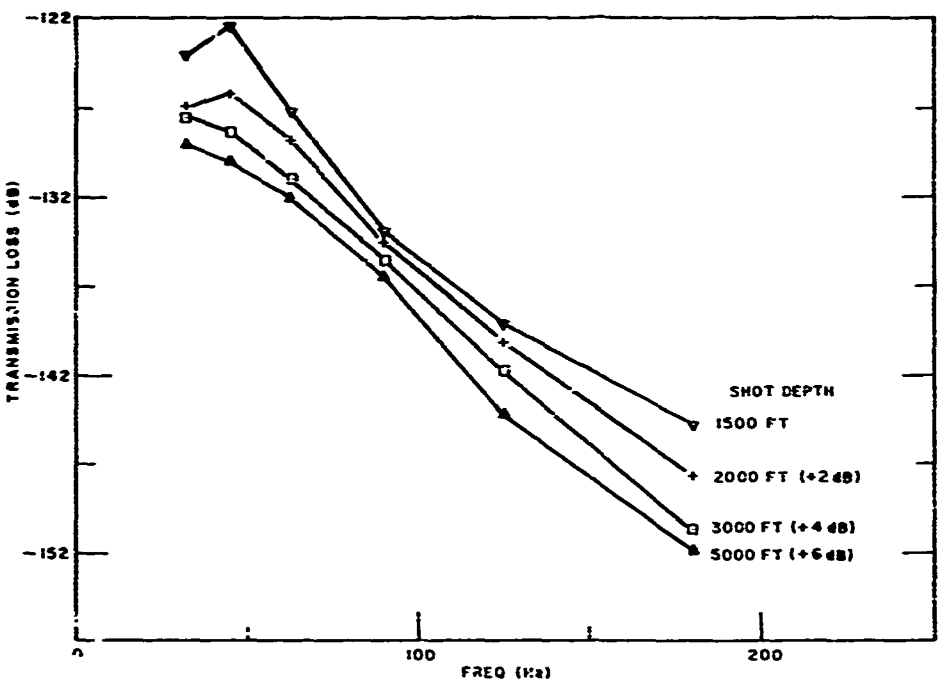

Fig. 27. Transmission loss. 15 lb DSS, NZ 2/2, range 50 n.m.

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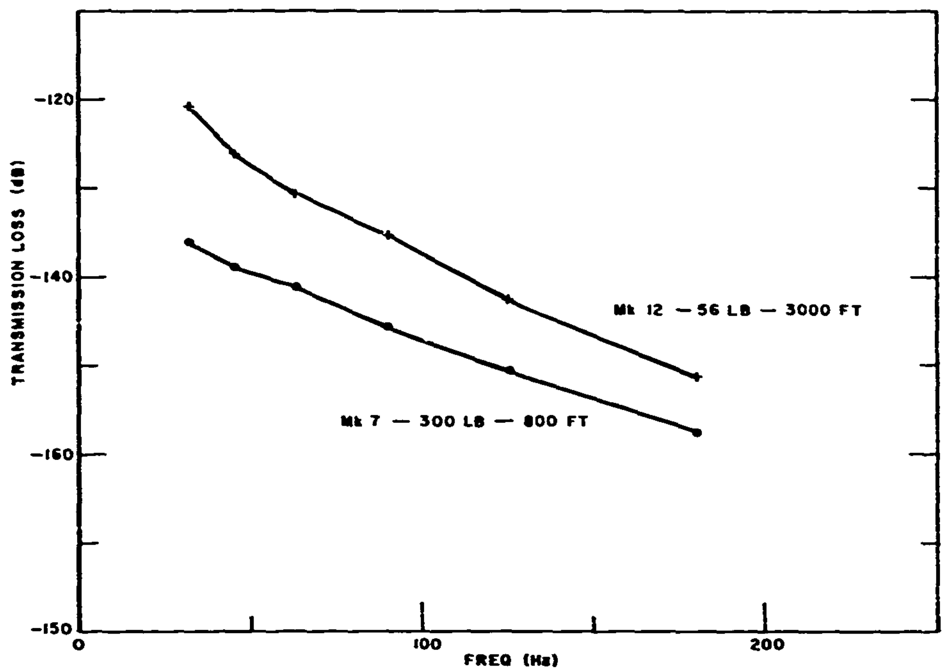

Fig. 28. Transmission loss, NZ 3, range 5070 n.m.

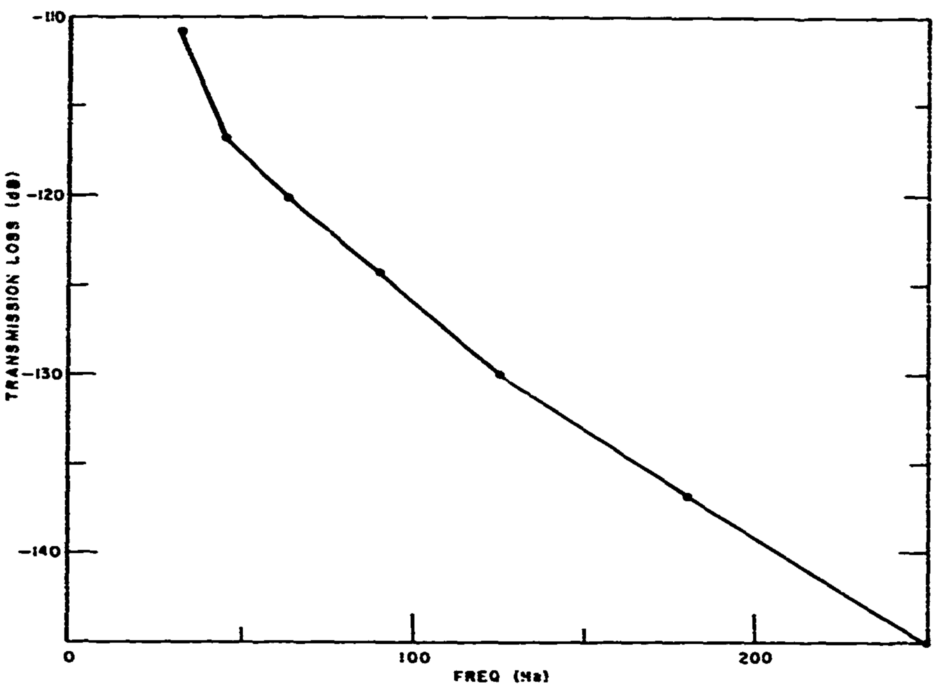

Fig. 29. Average transmission loss, HW 1, Mk 61 PDC 1.8 lb TNT, 800 ft depth, average range 3700 n.m.

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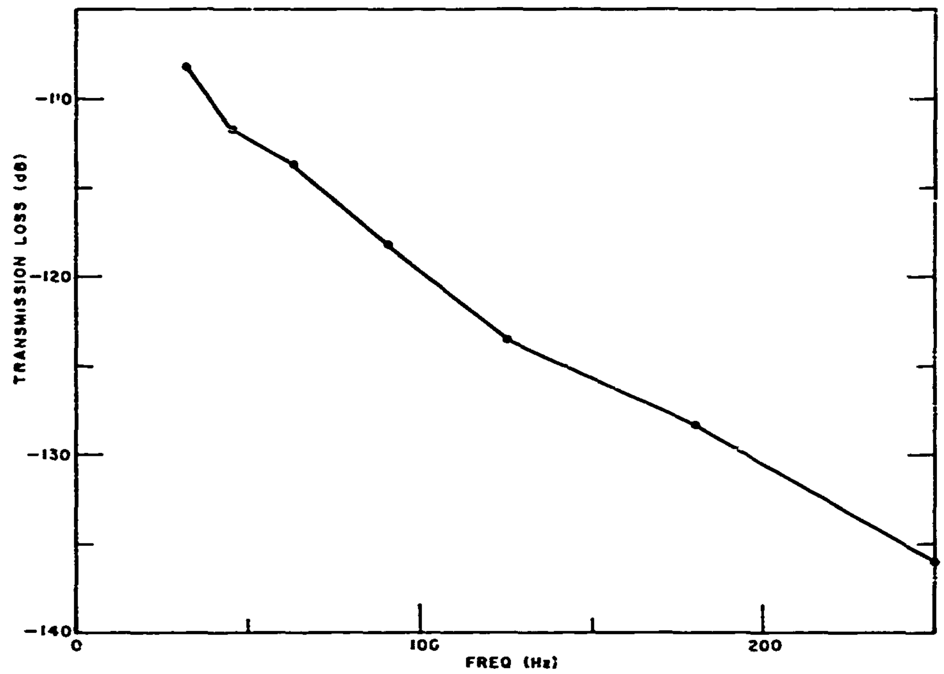

Fig. 30. Average transmission loss, HW 1, Mk 61 PDC 1.8 lb TNT, 300 ft depth, average range 3310 n.m.

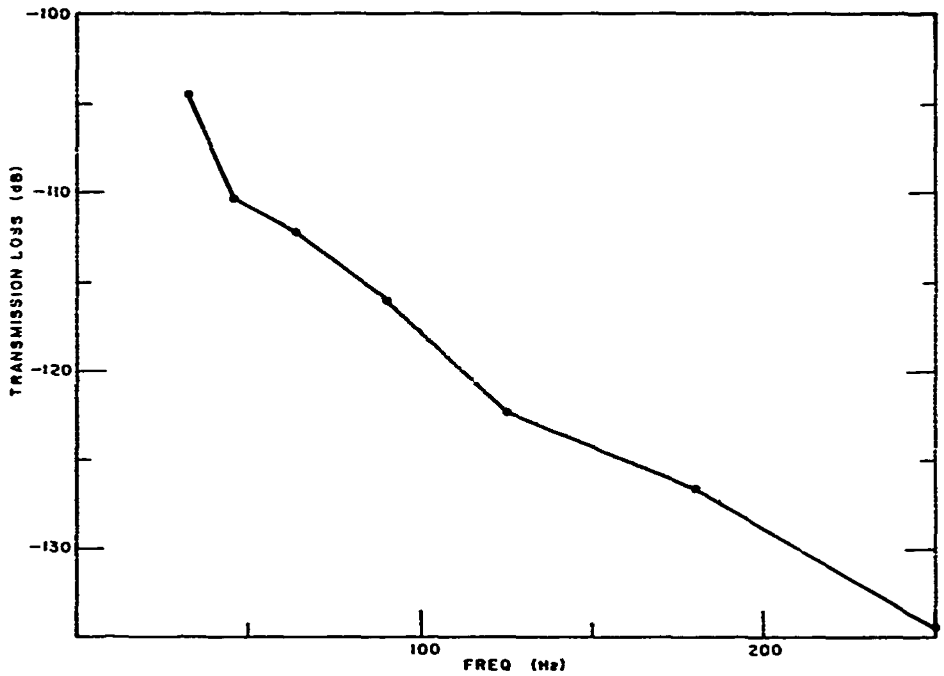

Fig. 31. Average transmission loss, HW 1, Mk 61 PDC 1.8 lb TNT, 800 ft depth, average range 3020 n.m.

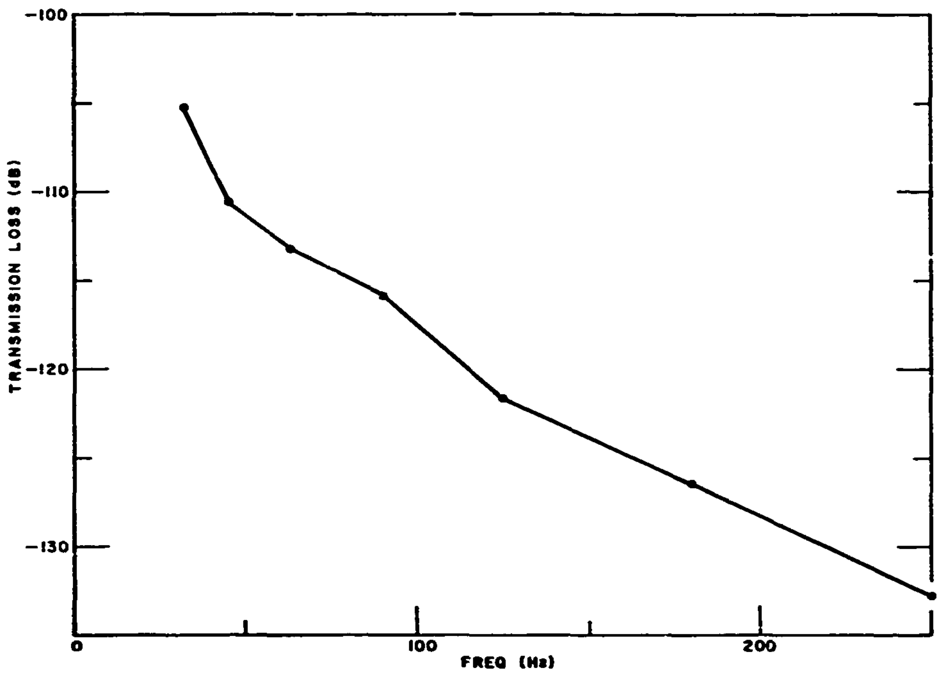

Fig. 32. Average transmission loss, HW 1, Mk 61 PDC 1.8 lb TNT, 800 ft depth, average range 2680 n.m.

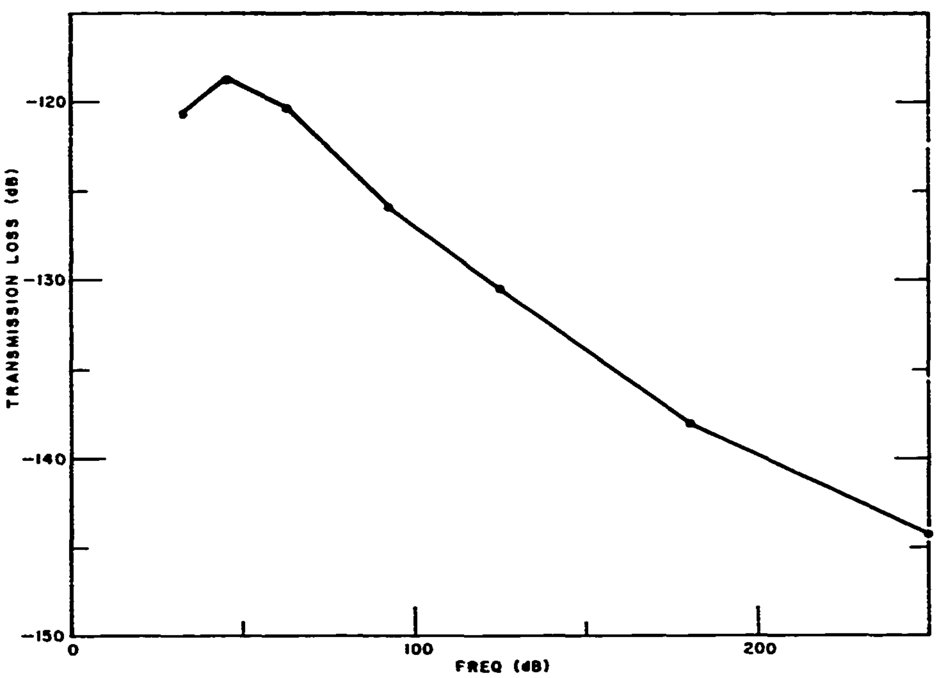

Fig. 33. Average transmission loss, HW 1, Mk 61 PDC 1.8 lb TNT, 60 ft depth, average range 2940 n.m.

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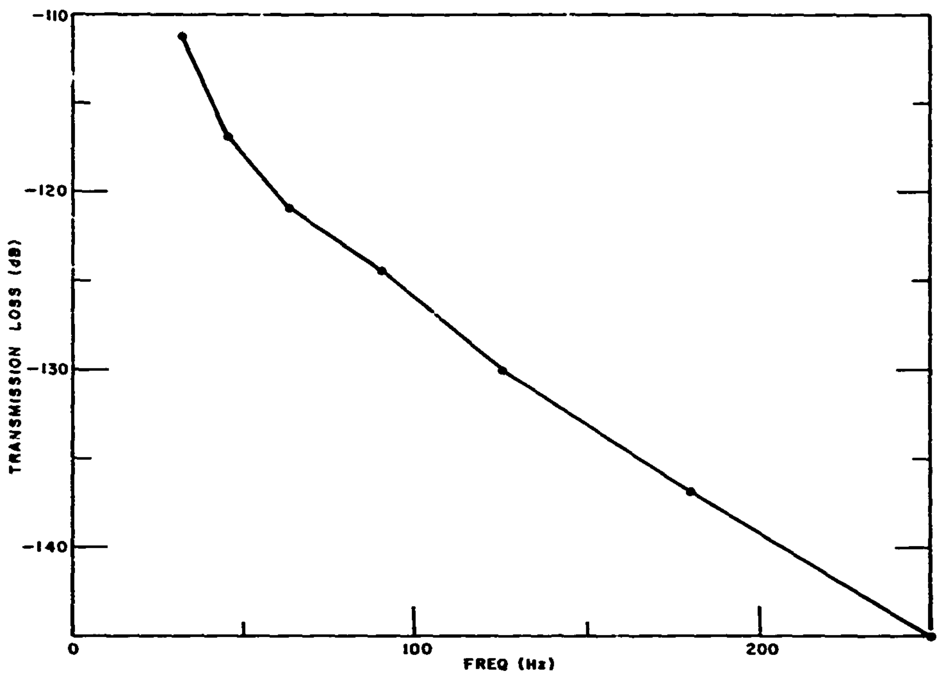

Fig. 34. Average transmission loss, HW 2/A, Mk 61 PDC 1.8 lb TNT, 800 ft depth, average range 4240 n.m.

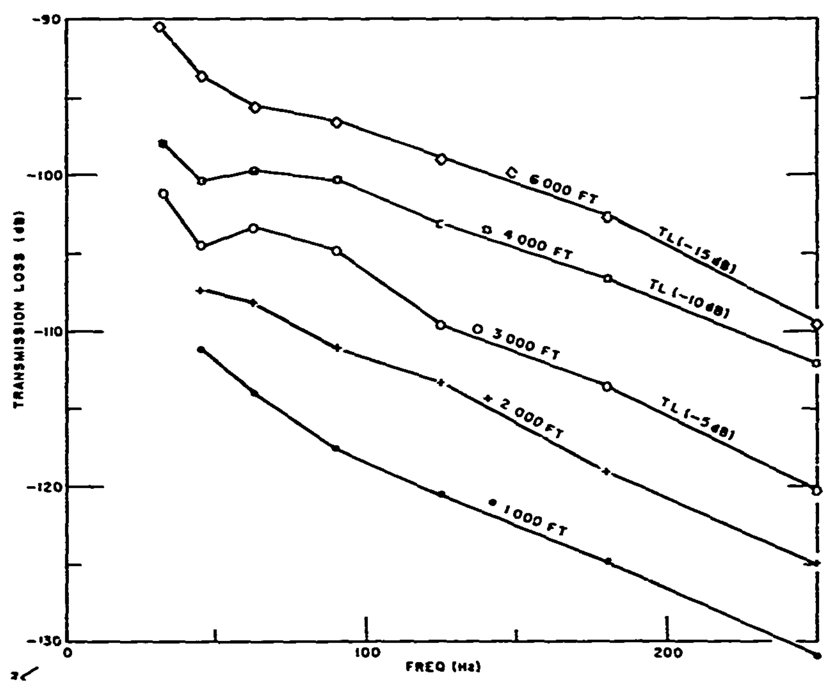

Fig. 35. HW 1A, Lady Lois DSS, Mk 59 4 lb TNT, range 2501.7 n.m.

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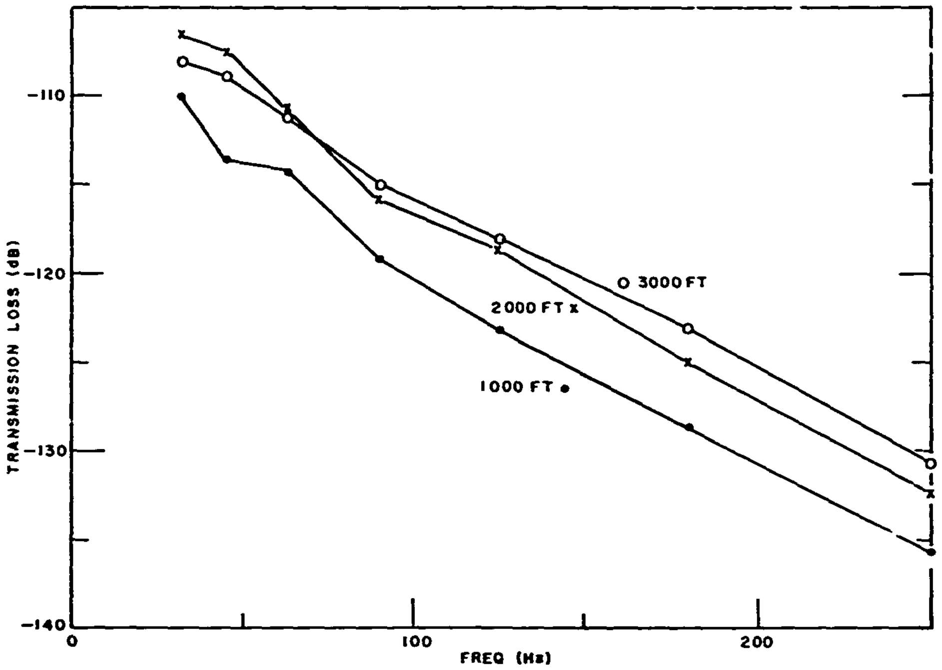

Fig. 36. HW 1A, Lady Lana DSS, Mk 59 4 lb TNT, range 3264.1 n.m.

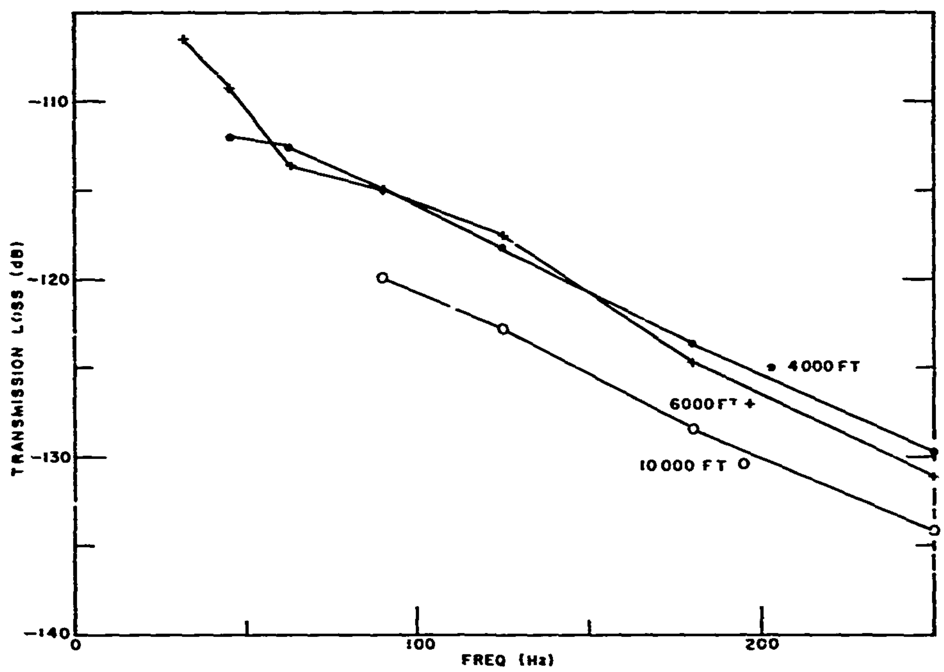

Fig. 37. HW 1A, Lady Lana DSS, Mk 59 4 lb TNT, range 3264.1 n.m.

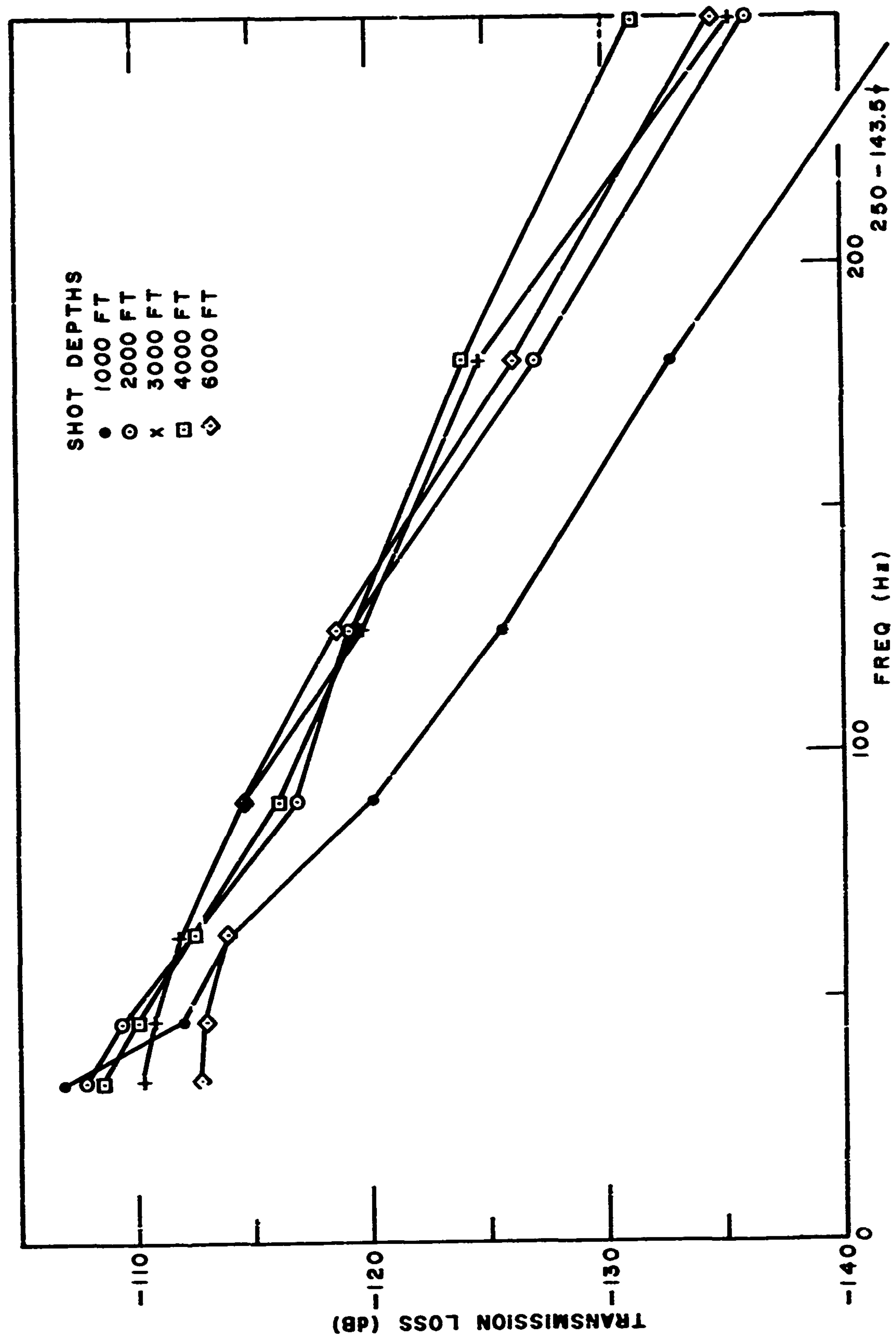

Fig. 38. HW 2A, Lady Betty DSS, Mk 59 4 lb TNT, range 4119.6 n.m.

through 25, it will be seen that the compensation for the source levels has removed the prominent curvatures found in the signal spectra. In fact, and within the measurement accuracy and certainly within the accuracy that can be assumed for the source spectra, the transmission loss spectra show a linear attenuation with frequency over the frequency range from 50 to 250 Hz. This is true for both the HW and the NZ serials. As expected, the low-frequency data, e.g., the data obtained using the 32 and 45 Hz filters, show less systematic trends than the higher frequency data. We believe this is primarily because of inaccurate calibration of the low-frequency source spectrum.

Table II summarizes the frequency decrements of the transmission loss spectra for the various acoustic serials of APTERYX. These data were obtained by using a straightedge to approximate the average slope of the curves. When the decrements are normalized with respect to the range of the acoustic source, they yield an average value of 3.5 dB/n.m.-Hz. Some spectra seem to show a slight $(\text{frequency})^2$ dependence, but this tendency is not consistent and could easily arise from the uncertainties in the source spectra.

VII. SOUND FIELD CALCULATIONS

It has been noted in preceding sections that the acoustical propagation measured during APTERYX represents cylindrical spreading of a sound field that is confined in its vertical intensity distribution within a depth interval of the ocean determined by the Pacific sound channel. Physical evidence for this confinement is provided by the increased transmission losses measured either for the shallow shot sources or the very deep sources. The trapping

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Table II.

Frequency Dependent Attenuation of APTERYX

Transmission Loss Spectra

Serial	Range (n. m.)	Charge Weight (lb)	Charge Depth (ft)	Decrement per 100 Hz	Decrement per Hz-n. m.
NZ 2/1	5070	300	3000	16.7	3.3×10^{-5}
NZ 2/1	5070	56	3000	19.3	3.8
NZ 2/1	5070	300	800	17.6	3.5
NZ 2/2	5070	15	DSS	16.8	3.3
NZ 3	5070	300	800	14.5	2.9
NZ 3	5070	56	3000	18.0	3.5
HW-1	3700	1.8	800	13.2	3.6
HW-1	3310	1.8	800	11.6	3.5
HW-1	3020	1.8	800	11.7	3.9
HW-1	2680	1.8	800	10.5	3.9
HW-1	2940	1.8	60	12.0	4.1
HW-2	4240	1.8	800	13.2	3.1
LOIS	2502	4.0	DSS	9.4	3.8
LANA	3264	4.0	DSS	10.5	3.2
BETTY	4120	4.0	DSS	13.0	3.2
				Average	3.5×10^{-5}

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of the energy within the sound channel was also demonstrated by ray tracing calculations computed using the Hudson Laboratories predictive model for the acoustical path from the location of the receiving hydrophone at 3300 ft, established by the Gibbs at GA site "A," to the position of the sound sources provided by RNZFA TUI during Serials NZ-2 and NZ-3.

The environmental data used in the program were not precise. This is due to the lack of data for the 5070-n.m. path length across a relatively unsurveyed ocean. Sound velocity profiles at the origin were obtained from data taken by the Gibbs at site GA "A," and Dr. A. C. Kibblewhite of NRLNZ provided sound velocity data for the NZ area. In between, sufficient data were found in the NODC files for the South Pacific to be able to construct a set of sound velocity profiles over the entire path. Similarly, bathymetric data were obtained by searching all available charts. While the environmental data are not based on a dense mesh of specific measurements, it is believed that they are highly representative for the propagation paths. The East Pacific Rise to the west of station "A," for example, appeared as a gentle rise with a minimum depth of 1500 fathoms at a range of 1660 n.m. from station "A." Documentation of the environmental data is not given in this report but is filed in Hudson Laboratories analysis library as no. 154 RT-1.

Specific features of the calculation are:

1. From the origin at station "A" with a depth of 1880 fathoms to the minimum depth of 1500 fathoms at range 1660 n.m., the bottom profile formed a shallow basin having a maximum depth of 2300 fathoms. As a result the deeper rays of the sound field, i.e., those specified by their angular elevation at the origin, interacted strongly with the bottom so that, at 1500 n.m., all rays with initial angles greater than ± 11.0° had been

terminated. The decision for termination was made if the net bottom attenuation reduced the ray intensity to less than 0.05 of its unattenuated value. With reference to Fig. 1, it can be seen that termination of the rays deeper than 3400 m will also terminate rays with depths less than 250 m.

2. After transit across the minimum depth of the East Pacific Rise, the deeper rays were further terminated so that at range 2000 n.m. from the origin only the rays with initial angles in the interval ± 10.2° remained to contribute to the sound field, and the minimum depth of these rays was 450 m. Also, and due to the gentle slopes assumed for the bathymetric profile, there was little conversion of steep ray angles into shallow ray angles following bottom reflections. Because of this, only the rays with initial angles in the intervals ±(9.4° to 10.2°) had been attenuated by bottom interactions and the remaining aperture, from -9.4° to +9.4°, had propagated entirely by refraction within the sound channel.

3. In propagation to the position of RNZFA TUI the sound field remained within the aperture set by the East Pacific Rise. The deepest rays were bottom refracted at depths of 1000 m above the ocean bottom. The sound velocity profiles at the farthest ranges began to show a less pronounced thermocline so that the minimum depth of the rays gradually decreased to about 100 m; even so, these near-surface depths were achieved by the rays with initial angle intervals ±(9.4° to 10.2°) and these are just the rays that had been bottom attenuated in passage across the East Pacific Rise.

4. The computed travel time variations within the sound channel aperture covered an interval of 6 sec and this is in excellent agreement with the width of the monitored shot signals.

5. The transmission loss as a function of depth at the TUI position was computed using the Type-III computation of the Hudson Laboratories programs. The results are presented in Fig. 39 and represent averages taken over a 600-m depth interval. In view of the lack of precise data for the upper thermocline and uncertainty as to the degree by which the shallow depth rays were attenuated at the East Pacific Rise, the curve of Fig. 39 has not been extrapolated to depths less than 200 m.

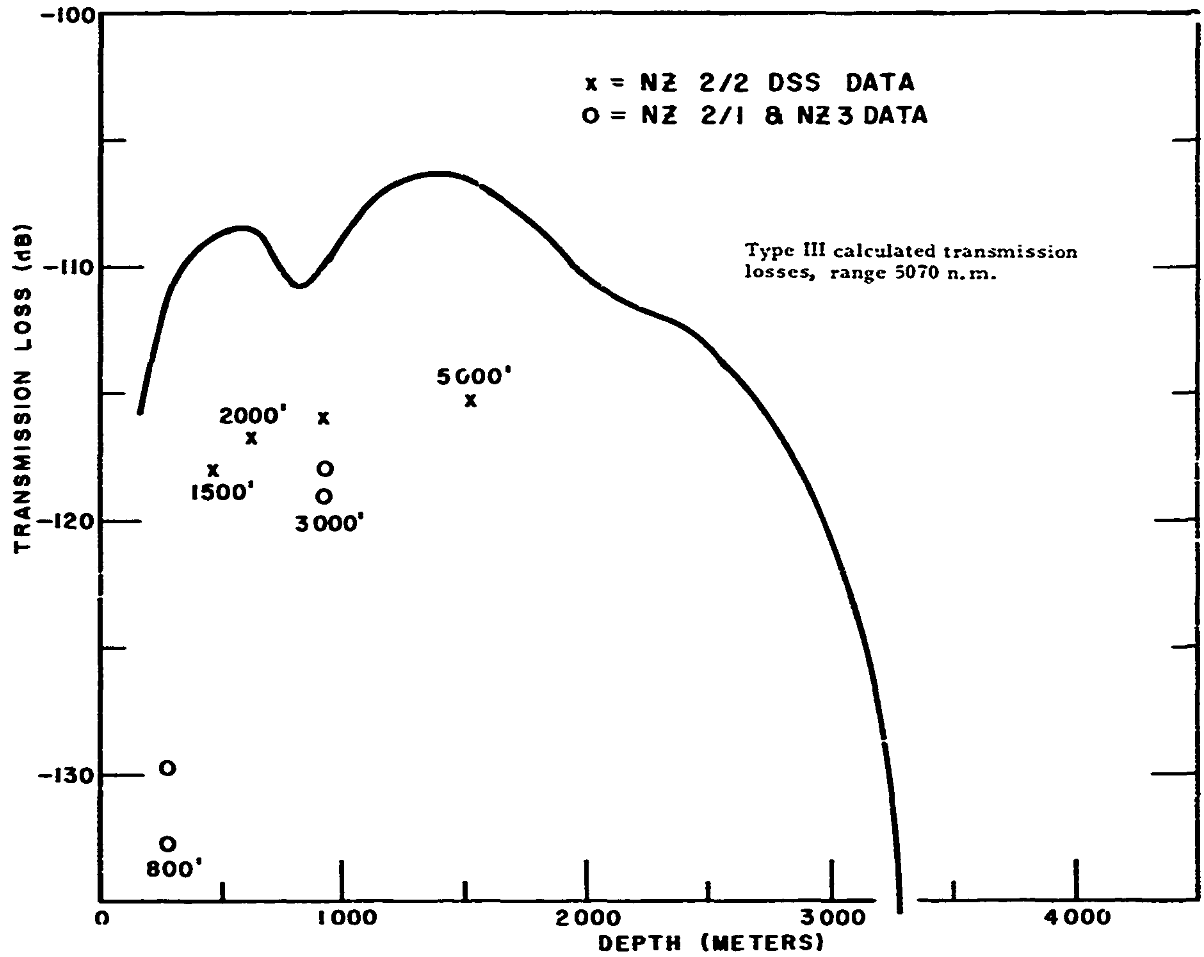


Fig. 39. The curve gives the vertical distribution of the transmission loss calculated by Hudson Laboratories programs, but without correction for absorption. The data points shown on the figure are from the NZ acoustic serials, but are corrected for the frequency-dependent attenuation summarized in Table II.

Unfortunately, it was not possible to carry out similar calculations for the acoustic paths from station GA "A" to the HW area. It is expected, however, that the propagation would also be entirely in the sound channel with aperture limiting by the East Pacific Rise to the northwest of station "A." Except for the limited detection of the 60-ft Mk 61 PDC charges at a range of 2940 n.m., there is no indication in the experimental data that energy in the sound channel over this path could show appreciable acoustic coupling to near-surface waters.

If it is accepted that the spreading sound energy travels entirely within the sound channel, with negligible bottom interaction, then the data of APTERYX can be used to determine sound absorption coefficients for underwater propagation. Let the absorption be represented by

$$I = I_o 10^{-\alpha R} \tag{2}$$

where R is the range in n.m. and α is expanded as a function of frequency as

$$\alpha = \frac{a}{f} + b + cf \quad . \tag{3}$$

The a/f term in (3) represents low-frequency attenuation due to normal mode effects, as discussed by Kibblewhite and Denham, but the physical origin of the remaining two terms is not clear. However, the frequency dependence of the absorption on these latter terms has been found in other experiments. It is emphasized that this absorption applies only as a range/frequency correction and the intensity measured in a sound field will also possess a vertical distribution that depends on the refraction due to the sound velocity field structure.

The transmission losses determined for the NZ serials were corrected for the frequency-dependent absorption due the term cf in (3), using the data of Table II, and are shown in Fig. 39 together with the results of the Type-III calculation. The latter, of course, represents spreading losses and aperture limiting of the sound field - the calculations did not include an absorption term that is normally inserted in the program. The constant b in (3) can be determined from Fig. 39 as an offset of approximately 8 dB, or a decrement of 0.0016 dB/n.m. Table II determines c to be 3.5×10^{-5} dB/n.m. - Hz.

The normal mode term, a/f in (3), was not clearly determined by the APTERYX data, largely because of the difficulties in making the low-frequency measurements during the experiment and also because of uncertainties in the low-frequency source spectra. The linear trend of the transmission loss curves appears well established to frequencies as low as 50 Hz, however, and if experimental error conceals a low-frequency fall off of the order of 1 dB, the NZ data indicate that the constant a must be less than 0.08 dB-Hz/n.m. The values of the three constants a, b, and c are summarized in Table III and compared with independent data.

VIII. CONCLUSIONS

It is believed that the data presented in Sections V, VI, and VII justify the summary and conclusions presented in Section II.

Table III.

Absorption in Long-Range Underwater Sound Propagation Due to Purely Refracted Underwater Paths.

The constants a, b, and c are parameters of a frequency-dependent absorption of the form

$$10 \log_{10} \frac{I}{I_o} = -R\left(\frac{a}{f} + b + cf\right)$$

for R in n.m. and f in Hertz.

Source	a	b	c
APTERYX	<0.08	1.6×10^{-3}	3.5×10^{-5}
Kibblewhite and Denham	0.18	13.6×10^{-3}	3.74×10^{-5}
Urick	--	3×10^{-3}	1.6×10^{-5}

APPENDIX A

OPERATION ORDER NO. 245

PROJECT APTERYX

I. OBJECTIVES

Project APTERYX is the code name for a test of long-range acoustical propagation in the North and South Pacific Ocean that is carried out as a coordinated operation between research laboratories and Navy operational commands. The purpose of APTERYX is to determine the efficiency of long-range propagation paths in the Pacific with respect to the bathymetric limitations and the velocity profiles that prevail over the principal acoustic paths. These data will have application towards the evaluation of acoustic transmission for purposes of surveillance in the ocean areas monitored during the experiment.

II. PARTICIPATING LABORATORIES AND COMMANDS

The program for APTERYX will be the responsibility of the following groups:

a) New Zealand Naval Research Laboratory (NRLNZ) will:

1) provide and monitor listening stations at designated locations on the Mahia Peninsula, and

2) will generate explosive shots in the New Zealand area as event schedules NZ1 through NZ6 from the RNZFA (Royal New Zealand Fleet Auxiliary) TUI and aircraft of the New Zealand Air Force.

b) Scripps Institution of Oceanography (MPL) will use the research platform FLIP as a listening station south of Hawaii and will use their continental communications facilities to transmit messages to GIBBS and PMR (Pacific Missile Range, Kaneohe) if necessary.

c) Hudson Laboratories will use the USNS J. W. GIBBS (T-AGOR-1);

1) to generate explosive shot sequences and carry out a cw projector tow in the GA area, and will

2) monitor the other source events from two anchor positions; A and B in the GA area in the Southeast Pacific.

d) COMASWFORPAC will coordinate explosive shot sequences with FAIRWINGSPAC and VP-6 from aircraft (A/C) drops and will obtain bathythermograph data over principal propagation paths during HW phases.

e) COMOCEANSYSPAC (COSP) will obtain and record shot transmission data from Pacific coast SOSUS stations for runs HW-1 and HW-3.

f) Pacific Missile Range (PMR) will monitor shot sequences from HW-2 and forward these data to Scripps (MPL), and will monitor shot sequences HW-1 and HW-3 at Kaneohe and forward these data to NAVOCEANO.

g) NAVOCEANO will analyze data from all COSP records obtained in e) above, and the PMR data indicated in f) above.

III. SENIOR SCIENTISTS (AND LOCATIONS DURING APTERYX)

Sr. Scientist on GIBBS	Dr. W. A. Hardy, Hudson Labs. Code Identifier - Sinbad Hotel
Sr. Scientist at NRLNZ	Dr. A. Kibblewhite, NRLNZ Code Identifier - Sinbad Kilo
Sr. Scientist on FLIP	Mr. Wm. Whitney, MPL (Scripps) Code Identifier - Sinbad Whiskey
Military Coordinator	Lt. G. Sharp, ASWFORPAC Code Identifier - Chico Sierra
Project Coordinator	Mr. G. H. Fisher, Hudson Labs. Code Identifier - Chico Foxtrot

Mr. G. Fisher will be located at PMR, Kaneohe, Hawaii.

Lt. G. Sharp will be located at COMASWFORPAC, Pearl Harbor, Hawaii.

Both day and night telephone numbers will be provided when available.

IV. PLAN OF EXPERIMENT (See Charts - Figs. 2, 3, and 4, pp. 4, 6, and 7 of this report)

APTERYX will involve both acoustic sources and listening stations that are located in three primary operational areas that are designated as follows:

1. NZ. The New Zealand area looking to the northern part of the Southwestern Pacific Basin from the Mahia Peninsula. The receiving array known as TABLE LAY is located at 39°06' S, 178°15' E.

2. HW. The Hawaii area contained within the boundaries Hawaii to Midway to Kwajalein to Hawaii and also specifying range runs 1500 miles eastward from Hawaii. FLIP and its receiving array will be positioned at approximately 17°30' N, 157°30' W.

3. GA. The area off the west coast of South America monitored by the GIBBS at two anchor stations, A and B on the charts, with an acoustic source tow between these. Station A will be near 2°30' S, 90°00' W. Station B will be near 21°30' S, 83°00' W. The final locations for A and B will be transmitted to the Project Coordinator once the GIBBS has surveyed for a suitable site and has anchored.

The principal acoustic paths to be tested during APTERYX are:

1. The Southern Pacific paths from NZ to GA.

2. The equatorial crossing paths from the HW area to GA.

3. The paths in the Central Pacific that lie South and to the West of the Hawaiian chain and contain the Marcus-Necker Ridge.

4. The paths from east of Hawaii to the Pacific Coast stations.

5. The acoustic paths between the NZ area and the HW area that are not shadowed by the intervening islands and archipelagos.

Detailed specifications of the source series and schedules appropriate to each of the operating areas follow in this Operational Order with references to the positions given in the charts (Figs. 2-4).

V. SCHEDULE SERIES (See Figs. 2-4)

The source schedules are further broken down into the following series, with explosive shots acting as sources for the NZ and HW series and both explosive shots and a projector tow for the GA series.

EVENTS

NZ1 - New Zealand aircraft run from TABLE LAY towards Sta. A.

NZ2 - TUI shots when GIBBS is at Sta. A.

NZ3 - TUI shot run with GIBBS at Sta. A.

NZ4 - TUI shots with GIBBS at Sta. B.

NZ5 - TUI shot run with GIBBS at Sta. B.

NZ6 - New Zealand aircraft run with GIBBS at Sta. B.

GA3 - GIBBS towing 110 Hz projector with shots (every 2 hours) and depth shot sequences (DSS) once a day at 2000Z from Sta. B to A, with port call at Callao, Peru.

HW1 - U. S. VP aircraft, FLIP to Sta. A.

HW2 - U. S. VP aircraft, FLIP to Midway to Kwajalein to FLIP (divided into three parts: HW2-A, HW2-B and HW2-C. These are three flights to be flown on three consecutive days.).

HW3 - U. S. VP aircraft, FLIP towards Sta. B.

VI. OPERATIONAL SCHEDULE OUTLINE

All times in ZULU*

February	12/2000	DSS for NRLNZ test (off Ecuador)
	14/2000	DSS for NZ test (off Ecuador)
	18/2000	Commence Communication Tests between operating areas
	20/2000	DSS vicinity of Sta. B
	20/2100	Super Event vicinity of Sta. B
	20/2130	Super Event vicinity of Sta. B
	21/1100	DSS from Sta. B
	22/1800 to 23/0058	HW3 (FLIP toward Sta. B) First Shot at 22/1800 at LADY BARBARA Last Shot at 23/0058 at LADY DAWN
	23/0400 to 24/1600	NZ4 and NZ5 (TUI)
	24/1740 to 25/0023	HW2-A (FLIP to Midway) First Shot at 24/1740 at LADY BETTY Last Shot at 25/0019 at SUSAN
	25/0300 to 25/0800	YOYO from Sta. B
	25/1858 to 26/0003	HW2-B (Midway to Kwajalein) First Shot 25/1858 at TERRY Last Shot 26/0003 at MARY
	26/0200 to 26/1000	NZ6 (NZ A/C toward Sta. B)
	26/1200 to 26/1700	YOYO from Sta. B

* EVENT positions are shown in Figs. 2-4.

February	26/1858 to 27/0215	HW2-C (Kwajalein to FLIP)
		First Shot 26/1858 at JOAN
		Last Shot 27/0215 at LULU
	27/2000	DSS from Sta. B
	27/2100	Super Event from Sta. B
	27/2130	Super Event from Sta. B
	28/0200	Commence GA 3 (tow from B to A with one day port call at Callao)
		Follow GA Schedule, Section VII-A
March	11/0700	Terminate GA 3
	11/2000	DSS vicinity of Sta. A
	11/2100	Super Event vicinity of Sta. A
	11/2130	Super Event vicinity of Sta. A
	12/1100	DSS from Sta. A
	13/1100 to 14/2300	NZ 2 and NZ 3 (TUI)
	15/0000 to 15/0800	NZ 1 (NZ A/C toward Sta. A)
	15/1000 to 15/1500	YOYO from Sta. A
	15/1700 to 15/2358	HW1 (FLIP toward Sta. A)
		First Shot 15/1700 at LADY LUCY
		Last Shot 15/2358 at LADY LOIS

NOTE: The above schedule outline consists of the major acoustic series that are given detailed specification below. However, many of the series interlace and run nearly continuously from one to the other, particularly in the period 22/1800 to 28/0200 and from 13/1100 to 15/2300. It has not been possible to make any allowance for schedule slippage due to the continuity of these sequences. If any event cannot be held because of weather or any other operational reason that event will either be canceled, rather than postponed, or will be shortened within its allotted time period. Every effort will be made to provide communications to give advance notice of such cancellations or shortenings through the Project Coordinator.

VII. DETAILS OF ACOUSTIC SCHEDULES

A. GA Schedules (GIBBS)

VII.A-1. GA-3 CW PROJECTOR TOW. From February 28/0200 to March 11/0700 the GIBBS shall tow a cw projector over the GA-3 track. In order to excite long-range propagation it will be necessary to tow the projector at the edge of or below the prevailing thermocline, requiring a tow depth of the order of 250 ft. Further, as the projector is an electromagnetic device operated resonantly, it is impossible to specify the exact frequency or power of the projector until it is placed in its operational environment, although nominal values are 110 Hz and 250 W. For these reasons the frequency, tow depth, and power of the projector will be tested prior to the operation phases and the measured values will be reported via the Project Coordinator to the listening groups, using the Communication Codes.

To maintain the 250 ft nominal tow depth it will be necessary to reduce the tow speed of the GIBBS to a value of the order of 6 knots, although the speed and tow depth will be adjusted by the Senior Scientist on GIBBS in accordance with the prevailing thermocline structure. Even so, it may be necessary to omit some sections of the overall towing track to permit the GIBBS to use full speed in order to arrive at Station A in the GA area by 11 March as a deadline for commencing subsequent operations. Tow interruptions of this type and interruptions due to breakdown or weather factors shall be communicated through the Project Coordinator.

VII.A-2. YOYO During each of the five-hour periods specified in the Schedule Outline a YOYO sequence shall be held from the anchored ship. This is a test of the excitation of the cw signals as a function of depth of the projector in the thermocline.

A YOYO sequence consists of:

Schedule time plus	Depth of projector (in feet)	
0000	500	projector on
0130	500	projector off
0140	400	projector on
0230	400	projector off
0240	300	projector on
0330	300	projector off
0340	200	projector on
0420	200	projector off
0430	100	projector on
0500	100	projector off

The projector depths for YOYO will be those of the above schedule, but frequencies and power will be determined by field tests and communicated prior to the first operational run on February 25/0300.

VII. A-3. DSS The DSS events from the GIBBS consist of a depth series of 15-lb Tetrytol shots fired between the surface and across the sound channel in accordance with the following schedule:

Shot No.	Designed Depth (in feet)	Time Overboard	Explosion Time
1	500	000	0001:40
2	100	0002	0004
3	250	0004	0006
4	500	0006	0007:40
5	1000	0008	0009:40
6	1500	0010	0012:30
7	2000	0012	0015:20
8	3000	0014	0019
9	5000	0016	0024:20
10	7500	0018	0030:30
11	10,000	0020	0036:40

It is to be emphasized that the depths and explosion times are nominal values and some variations, especially in the explosion times, are to be expected. Nonetheless, the shooters will attempt to adjust the sink rates and other factors in explosive handling so that the above schedule is followed as closely as possible. This will permit identification of the individual shots in the series from the received shot pattern.

DSS series other than those of the GA-3 tow will be fired from the GIBBS as indicated in the Schedule Outline on February 12/2000 and 14/2000 for test purposes in a general area off Ecuador, on February 20/2000 in the area of Station B during the site survey, and on February 21/1100 immediately prior to anchoring and launching the listening system. The DSS series on February 27/2000 will signal the subsequent Super Events, discussed below, and the start of the GA-3 tow.

During the GA-3 tow there will be a daily DSS series at 2000Z. Exceptions to this schedule will be communicated through the Project Coordinator. The DSS series of March 11/2000 will be held during site selection at Station A and that of March 12/1100 will be held immediately prior to anchoring at Station A.

VII. A-4. SINGLE SHOT SERIES During the entire GA-3 tow, commencing Feb. 28/0200 a 16 2/3-lb Nitramon shot will be fired every odd hour, ZULU, for an explosion depth of 500 ft and this series will be terminated March 11/0700. Exceptions to this schedule will be communicated to the Project Coordinator.

VII. A-5. SUPER EVENTS A Super Event is a 300-lb Tetrytol shot exploded at a depth of 3000 ft for testing reverberation levels due to terrain in the vicinity of the shot. The sinking time for these large shots is nominally 10 min, which must be added to the overboard times given in the Schedule Outline and below.

There are three scheduled Super Event pairs:

February 20/2100 - 20/2130 prior to anchoring at Station B

February 27/2100 - 27/2130 prior to start of GA-3 tow

March 11/2100 - 11/2130 prior to anchoring at Station A.

VII. A-6. NOTES

1. The DSS and single bi-hourly shot series will be held during GA-3 regardless of whether the projector is being towed or the ship is making full speed to reach Station A on schedule. That is, these events will be held on a fixed schedule independently of the towing condition.

2. The DSS of February 27/2000 may be delayed if unusual problems are encountered in retrieving listening gear and up-anchoring. In this case ONLY the scheduled 2000 DSS and subsequent Super Event pair will be delayed until the ship is underway and then will be used as a signal to indicate the start of the GA-3 tow. That is, if X is the delay encountered the schedule on February 27 shall be:

27/(2000 + X)	DSS from Sta. B
27/(2100 + X)	Super Event from B
27/(2130 + X)	Super Event from B
28/(0200 + X)	Commence GA-3 tow.

Insofar as possible notification of such delay shall be passed to the Project Coordinator.

3. During the GA-3 tow a one-day stop of the GIBBS will be made in Callao, Peru. During this day the projector tow, the 2000 DSS sequence, and the single bi-hourly shots at 500-ft depth will not be held. Advance notice of this interval will be given all operating groups through the Project Coordinator.

VII. B. NZ SCHEDULES

Due to difficulties in liaison the New Zealand source schedules and locations are not fully confirmed at this time. It has been determined that their schedules will integrate with the NZ periods given in the Schedule Outline, Section VI. Because the primary listening for the New Zealand signals will be from FLIP and GIBBS (and not from PMR or COSP facilities), the New Zealand schedules are not promulgated with this Operational Order, but the New Zealand Operational Order will be distributed to Scripps and Hudson for further forwarding prior to the start of APTERYX as a basis for the listening schedules for the NZ operations.

VII. C-1. HW SCHEDULES The HW series consists of aircraft from VP-6 flying the designated tracks and dropping explosive charges. The following procedures shall be followed during the drop portion of the flights.

a. Aircraft will maintain a 240-knot ground speed.

b. MK 61's will be dropped every 2 min (8 miles) on the even minute while flying the track.

c. The MK 61's will be set to detonate at alternate depths (800 and 60 ft) for the explosive shot sequences from A/C drops.

d. An additional MK 61, set for 800 ft, will be dropped at one minute past the hour.

e. Three additional MK 61's, set for 800 ft, will be dropped one minute apart to signify the start and finish of each track.

f. Several series of MK 59 MOD 1's and a 500-ft Canadian SUS will be dropped. These are identified as AD/DSS (AIR DROPPED DEEP SHOT SEQUENCE). Each series will consist of 7 charges to be dropped at 30 sec intervals:

Shot No.	Designed Depth (in feet)
1	300
2	1000
3	2000
4	3000
5	4000
6	6000
7	10,000

(Due to differences in sinking times, acoustic arrivals from the AD/DSS series will not be separated by the 30-sec drop time interval.)

g. After each AD/DSS, an Air Dropped BT will b dropped and monitored.

h. f and g above will be done while circling at the designated stations.

i. Rhumb lines will be flown between positions.

j. Should it be necessary for an HW series to abort, the A/C shall drop five 800 ft MK 61's at 30-sec intervals and also notify PMR by radio.

VII. C-2. TRACKS The tracks for the HW series are given on the detailed drop plan which is included with each track. Since the drop plans were laid out assuming a 240 knot ground speed, the schedule should be followed even though the A/C may not be at the exact geographical location that the plan indicates. This is important because all the recordings are done on a time basis.

VII. C-3. NOTES

1. Since FLIP will be slowly drifting, the positions for starting and finishing the tracks in the vicinity are to be in relation to FLIP and not a geographical location, i.e., Station LADY LUCY will be 25 n.m. from FLIP along a rhumb line towards LADY LANA.

2. Positions on the HW tracks are denoted by girls' names. Those that are prefixed by the word LADY, indicate that an AD/DSS and Air Dropped BT will take place at that station.

VII. C-4. DEPTH SETTINGS TO BE USED FOR MK 61's RELATIVE TO THE MINUTES OF THE HOUR DURING HW SERIES (EXCEPT WHILE CIRCLING FOR AD/DSS AND AIR DROPPED BT's).

TIME	DEPTH
00	800
01	800
02	60
04	800
06	60
08	800
10	60
12	800
14	60
16	800
18	60
20	800
22	60
24	800
26	60
28	800
30	60
32	800
34	60
36	800
38	60
40	800
42	60
44	800
46	60
48	800
50	60
52	800
54	60
56	800
58	60

VII. C-5. DROP SCHEDULE FOR HW1. FLIP TOWARD STA. A. 15 March 1967

START: LADY LUCY 17°28' N, 157°05' W (25 n.m. from FLIP along course)

LADY LANA 15°00' N, 144°45' W

END: LADY LOIS 11°50' N, 132°15' W

MILEAGE	TIME Z March		DEPTH	
0	15/1700	Commence circling at	800	Notification Shots
	1701	LADY LUCY	800	Start of Run
	1702		800	
	1704:00	Start AD/DSS at LADY	300	
	04:30	LUCY	1000	
	05:00		2000	
	05:30		3000	
	06:00		4000	
	06:30		6000	
	07:00		10,000	
	08	Air Drop BT & Monitor		
	1720	Commence regular shots	800	
	22		60	
	24		800	
728	26	etc. to LADY LANA	60	
	2022	Last regular shot	60	
		Commence circling at LADY LANA		
	2024	Start AD/DSS at LADY	300	
	24:30	LANA	1000	
	25:00		2000	
	25:30		3000	
	26:00		4000	
	26:30		6000	
	27:00		10,000	
	2028:00	Air Drop BT & Monitor		
	2040	Resume regular shots	800	
	42		60	
	44		800	
	46	etc. to LADY LOIS	60	
1496 n.m.	2350	AT LADY LOIS - LAST REGULAR SHOT	60	
(762 n.m.				
from	2351	Commence circling at	800	Notification Shots
LADY	2352	LADY LOIS	800	End of MK 61 run
LANA)	2353		800	
	2354	Start AD/DSS at LADY	300	
	54:30	LOIS	1000	
	55:00		2000	
	55:30		3000	

VII. C-5. DROP SCHEDULE FOR HW1 (Cont'd.)

MILEAGE	TIME Z		DEPTH
	56:00		4000
	56:30		6000
	57:00		10,000
	2358:00	Air Drop BT & Monitor END OF TRACK HW-1	

GEOGRAPHICAL LOCATIONS APPROXIMATE.

DROP SCHEDULES ARE PLANNED BY TIME, NOT DISTANCE.

VII. C-6. DROP SCHEDULE FOR HW2-A. FLIP TO MIDWAY. 24 February 1967

START: LADY BETTY 25 n.m. from FLIP along course

LADY IDA 20°25' N, 168°00' W

LADY SHEILA 23°00' N, 177°00' W

END: SUSAN 27°30' N, 177°00' W

MILEAGE	TIME Z February		DEPTH	
0	24/1740	Commence circling at	800	Notification Shots
	1741	LADY BETTY	800	Start of run
	1742		800	
	1744:00	Start AD/DSS at LADY	300	
	44:30	BETTY	1000	
	45:00		2000	
	45:30		3000	
	46:00		4000	
	46:30		6000	
	47:00		10,000	
	48	Air Drop BT & Monitor		
	1800	Commence regular shots	800	Hour mark
	1801		800	
	02		60	
	04		800	
	06	etc. to LADY IDA	60	
608	2032	Last regular shot Commence circling at LADY IDA	800	
	2034:00	Start AD/DSS at LADY IDA	300	
	34:30		1000	
	35:00		2000	
	35:30		3000	

VII. C-6. DROP SCHEDULE FOR HW2-A. FLIP TO MIDWAY (Cont'd.)

MILEAGE	TIME Z		DEPTH	
	36:00		4000	
	36:30		6000	
	37:00		10,000	
	2038:00	Air Drop BT & Monitor		
	2050	Resume regular shots	60	
	52	on run	800	
	54		60	
	56	etc. to LADY SHEILA	800	
1136 (528 n.m. from LADY IDA)	2254	Last regular shot. Commence circling at LADY SHEILA	60	
	2256:00	Start AD/DSS at LADY SHEILA	300	
	56:30		1000	
	57:00		2000	
	57:30		3000	
	58:00		4000	
	58:30		6000	
	59:00		10,000	
	2300:00	Air Drop BT & Monitor		Note: 2300 Hr mark shot omitted during this series
	2312	Resume regular shots	800	
	14		60	
	16		800	
	18	etc. to SUSAN	60	
1406 (270 n.m.	25/0020	AT SUSAN - LAST REGULAR SHOT	800	
from	21		800	Notification Shots
LADY	22		800	End of Run
SHEILA)	0023		800	

END OF HW2-A - AT SUSAN

VII. G-7. DROP SCHEDULE FOR HW2-B. MIDWAY TO KWAJALEIN

25 February 1967

START: TERRY 27°00' N, 178°00' W

LADY KAY 14°00' N, 171°40' E

END: MARY 12°00' N, 170°00' E

MILEAGE	TIME Z February		DEPTH	
0	25/1858		800	Notification Shots
	1859		800	Start of Run
	1900	Commence regular	800	Hour Mark
	1901	shots at TERRY	800	
	02		60	
	04		800	
	06	etc. to LADY KAY	60	
976	2304	AT LADY KAY - LAST REGULAR SHOT. Commence circling at LADY KAY	800	
	2306	Start AD/DSS at LADY KAY	300	
	06:30		1000	
	07:00		2000	
	07:30		3000	
	08:00		4000	
	08:30		6000	
	09:00		10,000	
	10	Air Drop BT & Monitor		
	2322	Resume regular shots	60	
	24		800	
	26		60	
	28	etc. to MARY	800	
1128 (152 n.m. from LADY KAY)	26/0000	AT MARY LAST REGULAR SHOT	800	
	01		800	Notification Shots
	02		800	End of Run
	0003		800	

HW2-B ENDS AT MARY

VII. C-8. DROP SCHEDULE FOR HW2-C. KWAJALEIN TO FLIP

26 February 1967

START: JOAN 10°00' N, 175°00' E

LADY DONNA 13°50' N, 171°00' W

END: LULU 25 n.m. before FLIP along course

MILEAGE	TIME Z February		DEPTH	
0	26/1858		800	Notification Shots
	1859		800	Start of Run
	1900	Commence regular shots	800	Hour Mark
	1901	at JOAN	800	
	1902		60	
	04		800	
	06	etc. to LADY DONNA	60	
864 n.m.	2236	AT LADY DONNA - LAST REGULAR SHOT Commence circling at LADY DONNA	800	
	2238:00	Start AD/DSS at LADY	300	
	38:30	DONNA	1000	
	39:00		2000	
	39:30		3000	
	40:00		4000	
	40:30		6000	
	41:00		10,000	
	42	Air Drop BT & Monitor		
	2254	Resume regular shots	60	
	56		800	
	58		60	
	2300		800	Hour Mark
	2301		800	
	02	etc. to LULU	60	
1656 n.m.	27/0212	AT LULU - LAST	800	
(792 n.m.		REGULAR SHOT		
from	13		800	Notification Shots
LADY	14		800	End of Run
DONNA)	0215		800	

HW2-C ENDS AT LULU

VII. C-9. DROP SCHEDULE FOR HW3. FLIP TOWARD STA. B

22 February 1967

START: LADY BARBARA 17°20' N, 157°05' W

LADY RUTH 11°58' N, 145°55' W

END: LADY DAWN 05°50' N, 134°50' W

MILEAGE	TIME Z		DEPTH	
0	22/1800	Commence circling at	800	Notification Shots
	1801	LADY BARBARA	800	Start of Run
	1802		800	
	1804:00	Start AD/DSS at LADY	300	
	04:30	BARBARA	1000	
	05:00		2000	
	05:30		3000	
	06:00		4000	
	06:30		6000	
	07:00		10,000	
	08	Air Drop BT & Monitor		
	1820	Commence regular shots	800	
	22		60	
	24	etc. to LADY RUTH	800	
728	2122	AT LADY RUTH - LAST REGULAR SHOT Commence circling at LADY RUTH	60	
	2124:00	Start AD/DSS at LADY	300	
	24:30	RUTH	1000	
	25:00		2000	
	25:30		3000	
	26:00		4000	
	26:30		6000	
	27:00		10,000	
	2128:00	Air Drop BT & Monitor		
	2140	Resume regular shots	800	
	42		60	
	44		800	
	46	etc. to LADY DAWN	60	
1496 n.m.	23/0050	AT LADY DAWN - LAST REGULAR SHOT	60	
(758 n.m. from LADY	0051	Commence circling at LADY DAWN	800	Notification Shots
RUTH)	52		800	End of MK 61 run
	53		800	

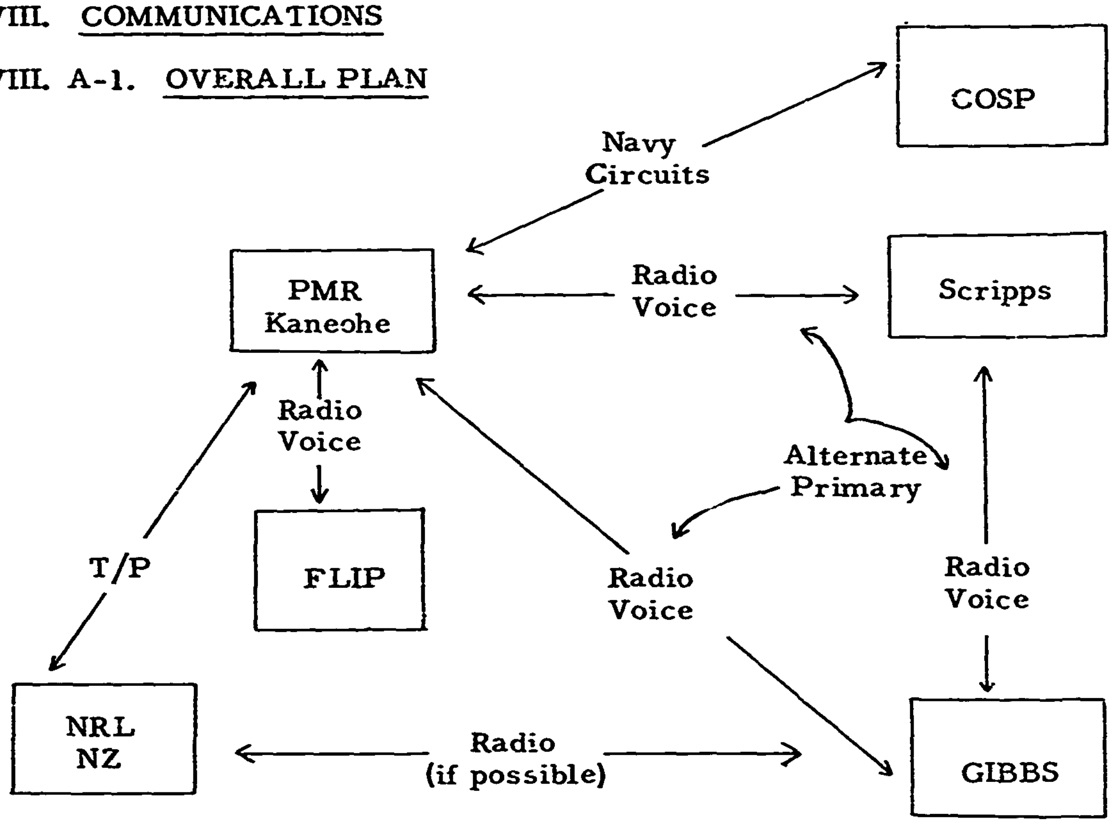
VII. C-9. DROP SCHEDULE FOR HW3 (Cont'd)

MILEAGE	TIME Z		DEPTH
	0054:00	Start AD/DSS at LADY	300
	54:30	DAWN	1000
	55:00		2000
	55:30		3000
	56:00		4000
	56:30		6000
	57:00		10,000
	0058	Air Drop BT & Monitor	

END OF HW-3 AT LADY DAWN

VIII. COMMUNICATIONS

VIII. A-1. OVERALL PLAN



VIII. A-2.

Facility	Call Sign
USNS J. W. GIBBS	GIBBS ONE
PMR Kaneohe	OUTRIDER
Scripps	WWD
FLIP	WI 7115
NRLNZ	NLE36

VIII. B. FREQUENCIES AND CHANNEL DESIGNATIONS

VIII. B-1. GIBBS, PMR, and Scripps will transmit and receive on:

Channel 1	4415.8 KC LSB (Alternate)
Channel 2	8805.8 KC LSB (Alternate)
Channel 3	12403.5 KC LSB (Secondary)
Channel 4	16533.5 KC LSB (Primary)

If authorization from CNO to PMR Kaneohe to use the above frequencies does not come through, PMR will receive on the above frequencies but will transmit on:

Channel 5	8088.5 KC LSB (Alternate)
Channel 6	12313.5 KC LSB (Secondary)
Channel 7	16418.5 KC LSB (Primary)

VIII. B-2. Messages between PMR and NRLNZ will be on a special teletype circuit (non-secure).

VIII. B-3. Radio frequencies between FLIP and PMR will be decided upon when Mr. W. Whitney of Scripps (MPL) visits PMR Kaneohe before boarding FLIP.

NOTE: If voice communications between GIBBS and PMR fail completely, including the alternate route through Scripps, messages shall be transmitted through Standard Navy Communication Nets.

VIII. C-1. COMMUNICATION TESTS

On February 18th, a series of transmission tests will take place between PMR, Kaneohe, GIBBS, and Scripps. The following schedule will be adhered to until a contact has been made between stations.

VIII. C-2. SCHEDULE FOR COMMUNICATION TESTS*

February 18, 1967

Time Z	Channel	Stations Involved
2000 - 2005	4	OUTRIDER TO GIBBS ONE
		GIBBS ONE also listens Ch. No. 7**
2005 - 2010	4	OUTRIDER TO WWD
		WWD also listens Ch. No. 7**
2010 - 2015	4	GIBBS ONE TO WWD
2020 - 2025	3	OUTRIDER TO GIBBS ONE
		GIBBS ONE also listens Ch. No. 6**
2025 - 2030	3	OUTRIDER TO WWD
		WWD also listens on Ch. No. 6**
2030 - 2035	3	GIBBS ONE TO WWD
2040 - 2045	2	OUTRIDER TO GIBBS ONE
		GIBBS ONE also listens Ch. No. 5**
2045 - 2050	2	OUTRIDER TO WWD
		WWD also listens on Ch. No. 5**
2050 - 2055	2	GIBBS ONE TO WWD

If no contact is made at this time, the schedule will be repeated three (3) more times at two (2) hour intervals, i.e., at 18/2200 Z, 19/0000Z, and 19/0200 Z. If no contact is made at these periods, the identical procedure will commence at 19/1700 Z.

* Tests with NRLNZ will be arranged by the Project Coordinator.

** Cross-band operation may be necessary if authorization for PMR to use Channels 1 through 4 is not obtained.

VIII. D-1. CODING

Messages pertaining to APTERYX will, for the most part, be passed over non-secure transmission links. In general, most of the messages should be in plain language using the designations of this document, i. e., DSS, YOYO, HW Series, etc. However, there are certain sensitive categories that will require further coding for non-secure messages.

In relation to GA3 and YOYO from the GIBBS, these are:

The acoustic projector

The acoustical output of the projector

The frequency of the projector

The depth of the projector.

In addition, geographical locations should never be given as to latitude and longitude but only in relation to a position or station listed in the Op Order.

VIII. D-2. The acoustic projector shall be referred to as ZIPPO.

VIII. D-3. The output, in acoustical watts, shall be given in accordance with the following:

POKER POT is even	=	300 W
POKER POT is minus 50 (chips)	=	250 W
POKER POT is plus 75 (chips)	=	375 W

etc.

VIII. D-4. The depth of the projector shall be expressed as the name of a city.

OMAHA	=	100 ft
STRATFORD	=	200 ft
DETROIT	=	300 ft

BUFFALO = 400 ft

HARTFORD = 500 ft

Any distance between these shall be expressed as miles before (less) or after (greater) the city name.

VIII. D-5. The frequency of the projector shall be given according to a numbered code. The random letters before the code number are there to serve only as a check for possible mistakes when transmitting the code.

The conversion tables for the code are on the following two pages, Sections VIII. F-1 and F-2.

Example: "ZIPPO Q66 is 35 miles before DETROIT, POKER POT is minus 100 chips."

This means that the projector has a frequency of 112.5 Hz, is at 265 ft, and has an acoustical output of 200 W.

VIII. E. COORDINATION

PMR, Kaneohe will be the center for communications during the operation. The Project Coordinator, Mr. G. H. Fisher, will be located here. It will be his responsibility to insure that all participating activities are advised of the progress of the operations and are notified, insofar as possible, of any schedule changes or modifications.

Lt. Grant Sharp, of ASWFORPAC, is the Military Coordinator and will be in constant touch with Mr. Fisher throughout APTERYX. Either Mr. Fisher or Lt. Sharp may be contacted at any time with any problems concerning APTERYX.

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VIII. F-1. CONVERSION TABLE

CODE TO FREQUENCY IN HZ

Code	Freq.	Code	Freq.	Code	Freq.	Code	Freq.
N01 =	129.0	A26 =	117.5	M51 =	103.5	B76 =	120.0
P02 =	146.0	W27 =	107.0	G52 =	108.0	F77 =	110.5
P03 =	140.5	Q28 =	109.5	L53 =	131.0	T78 =	104.5
X04 =	136.0	S29 =	124.5	Q54 =	137.0	A79 =	138.0
S05 =	121.0	B30 =	127.5	J55 =	138.5	T80 =	126.0
L06 =	104.0	V31 =	139.5	U56 =	119.5	E81 =	118.0
I07 =	141.5	X32 =	148.5	J57 =	127.0	F82 =	122.5
A08 =	132.5	X33 =	135.0	E58 =	109.0	O83 =	144.0
X09 =	126.5	U34 =	106.0	J59 =	125.5	R84 =	110.0
V10 =	102.5	P35 =	101.5	W60 =	142.0	D85 =	102.0
U11 =	114.5	E36 =	123.0	R61 =	135.5	S86 =	112.0
N12 =	118.5	P37 =	131.5	I62 =	120.5	B87 =	143.5
O13 =	108.5	K38 =	129.5	M63 =	116.0	K88 =	147.0
N14 =	147.5	I39 =	141.0	R64 =	107.5	A89 =	133.5
T15 =	134.0	W40 =	145.5	H65 =	146.5	G90 =	111.5
Z16 =	130.5	H41 =	136.5	Q66 =	112.5	W91 =	123.5
T17 =	116.5	O42 =	121.5	K67 =	113.0	R92 =	148.0
C18 =	105.0	B43 =	115.0	G68 =	128.5	Z93 =	125.0
C19 =	100.5	H44 =	103.0	U69 =	117.0	D94 =	133.0
G20 =	145.0	D45 =	130.0	L70 =	119.0	E95 =	100.0
C21 =	128.0	D46 =	140.0	V71 =	101.0	Y96 =	122.0
H22 =	115.5	J47 =	144.5	F72 =	114.0	I97 =	132.0
V23 =	111.0	S48 =	149.0	Q73 =	142.5	F98 =	106.5
Z[illegible] =	137.5	N49 =	134.5	M74 =	105.5	Y99 =	139.0
O25 =	143.0	M50 =	113.5	K75 =	124.5		

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VIII. F-2. CONVERSION TABLE

FREQUENCY IN HZ TO CODE

Freq. Code	Freq. Code	Freq. Code	Freq. Code
100.0 = E95	113.0 = K67	126.0 = T80	139.0 = Y99
100.5 = C19	113.5 = M50	126.5 = X09	139.5 = V31
101.0 = V71	114.0 = F72	127.0 = J57	140.0 = D46
101.5 = P35	114.5 = U11	127.5 = B30	140.5 = P03
102.0 = D85	115.0 = B43	128.0 = C21	141.0 = I39
102.5 = V10	115.5 = H22	128.5 = G68	141.5 = I07
103.0 = H44	116.0 = M63	129.0 = N01	142.0 = W60
103.5 = M51	116.5 = T17	129.5 = K38	142.5 = Q73
104.0 = L06	117.0 = U69	130.0 = D45	143.0 = O25
104.5 = T78	117.5 = A26	130.5 = Z16	143.5 = B87
105.0 = C18	118.0 = E81	131.0 = L53	144.0 = O83
105.5 = M74	118.5 = N12	131.5 = P37	144.5 = J47
106.0 = U34	119.0 = L70	132.0 = I97	145.0 = G20
106.5 = F98	119.5 = U56	132.5 = A08	145.5 = W40
107.0 = W27	120.0 = B76	133.0 = D94	146.0 = P02
107.5 = R64	120.5 = I62	133.5 = A89	146.5 = H65
108.0 = G52	121.0 = S05	134.0 = T15	147.0 = K88
108.5 = O13	121.5 = O42	134.5 = N49	147.5 = N14
109.0 = E58	122.0 = Y96	135.0 = X33	148.0 = R92
109.5 = Q28	122.5 = F82	135.5 = R61	148.5 = X32
110.0 = R84	123.0 = E36	136.0 = X04	149.0 = S48
110.5 = F77	123.5 = W91	136.5 = H41	
111.0 = V23	124.0 = S29	137.0 = Q54	
111.5 = G90	124.5 = K75	137.5 = Z24	
112.0 = S86	125.0 = Z93	138.0 = A79	
112.5 = Q66	125.5 = J59	138.5 = J55	

IX. DATA ACQUISITION

Responsibilities for DATA ACQUISITION during APTERYX are as follows:

1. NRLNZ, GIBBS (Hudson Labs), FLIP (Scripps MPL) — will obtain acoustic transmission data using their own hydrophone facilities and will process these data according to their standard research procedures.

2. PMR will:

   A. Record the complete shot series HW-2 at the following locations:

      i. PMR Wake Island, recording with the Sanborn and on magnetic tape at 3 ips, 3-5 dB above system noise, at sites no. 31, 32, 35, 37. Calibrations will be at 1.0 volts, 100 Hz.

      ii. PMR Eniwetok Island, recording as above at sites no. 41 and 44.

      iii. PMR Midway Island, recording as above at sites no. 20 and 25, with two level recording for each site.

At the conclusion of APTERYX these data, operating logs, and calibration records are to be sent to:

Scripps Institution of Oceanography
Marine Physical Laboratory
University of California
San Diego, California
Attn: Mr. William Whitney

   B. Record the shot series HW-1 and HW-3 at PMR Kaneohe using procedures requested by the Project Coordinator for APTERYX stationed at Kaneohe.

At the conclusion of APTERYX these data are to be sent to:

U.S. Naval Oceanographic Office
Exploratory Oceanography Division
Washington, D. C. 20390
Attn: Mr. D. Atkosius

3. COSP will record the shot series HW-1 and HW-3 in accordance with a Supplementary APTERYX Operational Order.

4. COMASWFORPAC (Acting with VP-6) will maintain operational logs of all A/C drops during HW-1, HW-2, and HW-3 and will forward these (or clear copies) at the conclusion of APTERYX to:

   Hudson Laboratories of Columbia University
   145 Palisade Street
   Dobbs Ferry, New York 10522
   Attn: Dr. Wilton A. Hardy

5. TUI (NRLNZ) and NRLNZ Aircraft will maintain source and navigational logs for all NZ series and at the conclusion of APTERYX will forward these (or clear copies) to:

   Hudson Laboratories of Columbia University
   145 Palisade Street
   Dobbs Ferry, New York 10522
   Attn: Dr. Wilton A. Hardy

6. GIBBS (Hudson Labs) will maintain source and navigational logs for the GA series. Additionally, at the conclusion of APTERYX Hudson will forward these and the logs from other participating groups that are received at Hudson Labs to the appropriate data reduction laboratories.

Signed by

G. H. Fisher
Executive Assistant
to the Director
Hudson Laboratories

Signed by

Wilton A. Hardy
Associate Director for
Underwater Acoustics
Hudson Laboratories

APPENDIX B

SOURCE LEVELS

For the most part, the properties of underwater explosions are well understood, and the far field waveform, i.e., the waveform at large distances from the shock wave, resembles that of the model waveform of Fig. B-1. The parameters of the waveform, which are also given in Fig. B-1, have been obtained from the standard scaling theory.[B1, B2] The waveform shown in the figure cannot be exactly correct, however, because the pressure p of an acoustic impulse in a fluid must obey the relationship

$$\int_{-\infty}^{\infty} p \, dt = 0 \tag{B1}$$

if there is no permanent displacement of the fluid particles. Weston has shown that the requirement of (B1), above, suppresses the very low frequency energy spectrum level, which can be expected to increase more rapidly than (frequency)^2.[B3]

In the waveform of Fig. B-1, the time delays between the successive pulses produce interferences in the energy spectrum. The latter is calculated as

$$\begin{aligned} E(\omega) = \frac{2}{\rho c} \Bigg\{ & \frac{P_o^2 \tau_o^2}{1+\omega^2 \tau_o^2} + \frac{4\tau_b^2}{(1+\omega^2 \tau_b^2)^2} (P_1^2 + P_2^2) + \frac{8\tau_b^2 P_1 P_2}{(1+\omega^2 \tau_b^2)^2} \cos \omega \tau_2 \\ & + \frac{4P_o P_1 \tau_o \tau_b}{(1+\omega^2 \tau_o^2)(1+\omega^2 \tau_b^2)} (\cos \omega\tau_1 + \omega\tau_o \sin \omega\tau_1) \\ & + \frac{4P_o P_2 \tau_o \tau_b}{(1+\omega^2 \tau_o^2)(1+\omega^2 \tau_b^2)} \left[\cos \omega (\tau_1 + \tau_2) + \omega\tau_o \sin \omega (\tau_1 + \tau_2)\right] \Bigg\} \end{aligned} \tag{B2}$$

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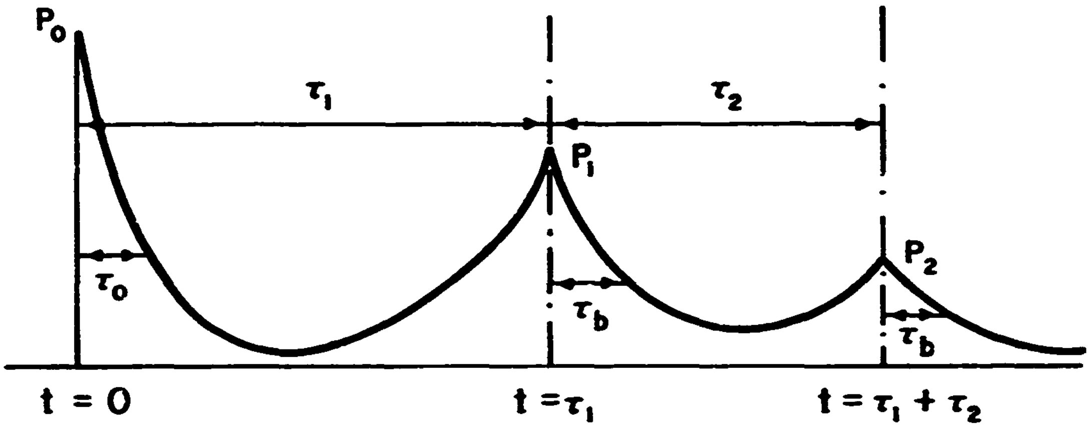

Fig. B-1. Superimposed exponential waveforms assumed for explosive shots. P_o, P_1, and P_2 are the peak pressures of the initial pulse and the first and second bubble pulses, respectively. The time constant of the initial pulse is τ_o and the time constant of the bubble pulse is τ_b. The bubble pulses are delayed by the intervals τ_1 and τ_2, as shown in the figure. If W is the weight of the charge in pounds and d is the depth of the charge in feet, the parameters of the waveform are given by scaling theory as:

$$\tau_o = 475\ W^{0.27} \times 10^{-6}\ \text{sec}$$

$$\tau_b = 1.4(33 + d)^{-1/6} \times 10^{-3}\ \text{sec}$$

$$\tau_1 = 4.36\ W^{1/3}(33 + d)^{-5/6}\ \text{sec}$$

$$\tau_2 = 0.72\ \tau_1$$

$$P_o = 1.48\ W^{0.377} \times 10^{8}\ \text{dynes/cm}^2\ \text{(ref. one yard)}$$

$$P_1 = \frac{P_o}{0.644} \frac{\tau_o}{\tau_b} W^{-0.314}(33 + d)^{-1/6}$$

$$P_2 = 0.212\ P_1 \quad .$$

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for an angular frequency ω . $E(\omega)$ has the units of ergs/cm^2/Hz and applies at the reference distance of one yard. ρc is the acoustic impedance. At low frequencies the largest interference term is the one that includes $\cos \omega\tau_1$. This term produces a maximum spectrum level for $\omega=0$ and this cannot be true, as shown by Weston.[B3] Nonetheless, the low frequency failure of Eq. (B2) must occur for frequencies much lower than the frequency $1/\tau_1$, which is also termed the bubble pulse frequency.

During an experiment carried out at the end of 1967, BOOMERANG V, Hudson Laboratories was able to obtain source spectra for a series of 1-lb TNT shots at explosion depths from the surface to 14,000 ft. The spectra were obtained digitally and, except for the frequency band below 30 Hz where hydrophone calibration data were poor, were corrected for the transfer functions of the measurement apparatus, again using digital techniques. The experimental source spectrum for a 1-lb shot at a depth of 3907 ft is shown in Fig. B-2. The low-frequency fall-off is clearly shown, but the bubble pulse interferences are more highly modulated in the experimental spectrum than would be predicted by Eq. (B2). This behavior was true for all the shots that were analyzed.

Equation (B2) was programmed for a digital computer so that the spectra of various shots could easily be run-off. Figure B-2 includes the predicted spectrum for the same shot, i.e., the 1-lb, 3907-ft shot, as a comparison. The agreement is rough, at best, and indicates that Eq. (B2) must be used with considerable caution.

The parameter dependences shown in Fig. B-1 indicate the dependence of the bubble pulse period τ_1 on the depth and weight of the shot. For the

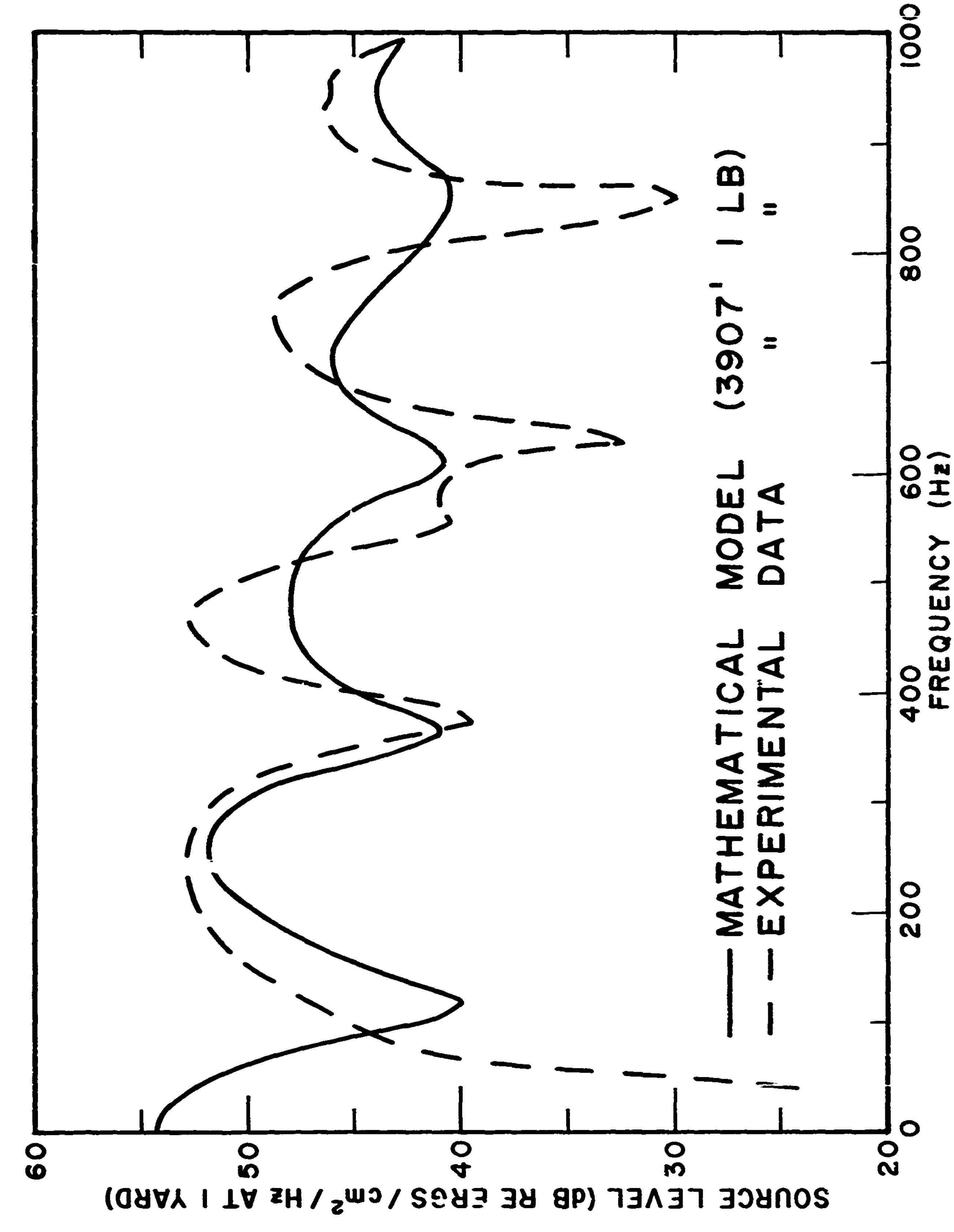

Fig. B-2. Comparison of calculated and measured spectrum of 1-lb TNT shot at depth 3907 ft.

air-dropped charges used in APTERYX, with weights of 1.8 lb or 4.0 lb, and for the charges at 800-ft depth or greater, the bubble pulse periods are measured in milliseconds and both the low-frequency intensity maximum and the succeeding interference minimum fall directly in the frequency analysis band of the experiment. This makes it difficult to obtain source spectra for these charges by calculation, not only because of the errors involved in the use of Eq. (B2) but because the specific explosion depths were not monitored. For example, if the 1-lb shot of Fig. B-2 had been monitored in a frequency pass band centered on one or the other side of the minimum at 375 Hz, there would have been a significant change of level monitored in the pass band if the shot depth varied by several percent.* The precise variation will depend on the depth of the shot and on the width of the pass band used in the analysis.

It is useful to note that these effects can be used to advantage for the design of experiments using explosives as acoustic sound sources. Thus, if a detailed low-frequency spectrum is desired, it is preferable to use small, deep shots to obtain a broad source spectrum that will be relatively insensitive to the shot depth variations. Conversely, the use of large, shallow shots together with broad frequency pass bands in the analysis, will provide averaging of the interferences and again will yield data that are insensitive to the shot depth variations.

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* The 375-Hz frequency of this example lies outside the frequency pass band used in APTERYX. However the APTERYX charges were larger and many occurred at shallower depths so that these interference minima did occur below 250 Hz.

The computer program for Eq. (B2) not only computed the source levels but additionally computed averages of these spectra over given pass bands. In integral form this average is

$$W(f_C) = \frac{1}{f_U - f_L} \int_{f_L}^{f_U} E(\omega) \frac{d\omega}{2\pi} \tag{B3}$$

where f_U and f_L are the upper and lower effective cutoff frequencies of the filter with a center frequency f_C . The specific bandwidths used in the calculation are given in Table I. The source spectra derived from these averages are shown in Figs. B-3 through B-8 for the shot weights and depths used in APTERYX. At low frequencies, where the computation clearly was in error through not predicting the $(\text{frequency})^{2+}$ fall-off required by Eq. (B1), the curves were amended by extrapolating from the intensity maximum to lower frequencies with a fall-off of 6-dB/octave. In view of Fig. B-2 and the above commentary, it must be emphasized that the spectra are approximations.

Aircraft-dropped shots are frequently used in transmission loss measurements such as those of APTERYX, and it is not practical to obtain specific source spectra of the individual shots. It can be recommended, however, that source spectra be obtained in a calibration location and not only for the nominal shot depths but over a range of depths about the nominal depth to determine the spectral shifts as a function of depth. The spectra should be measured either over the identical pass bands to be used in the experiment or, preferably, in detailed digital form so that the averages can be computed for pass bands of arbitrary shape.

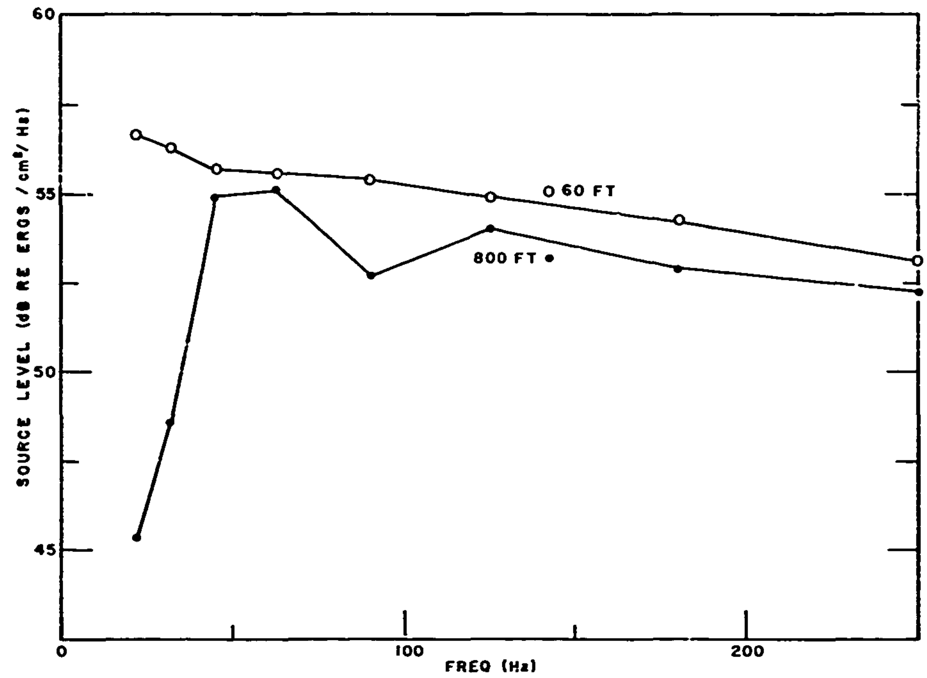

Fig. B-3. Spectral levels for 1.8 lb TNT.

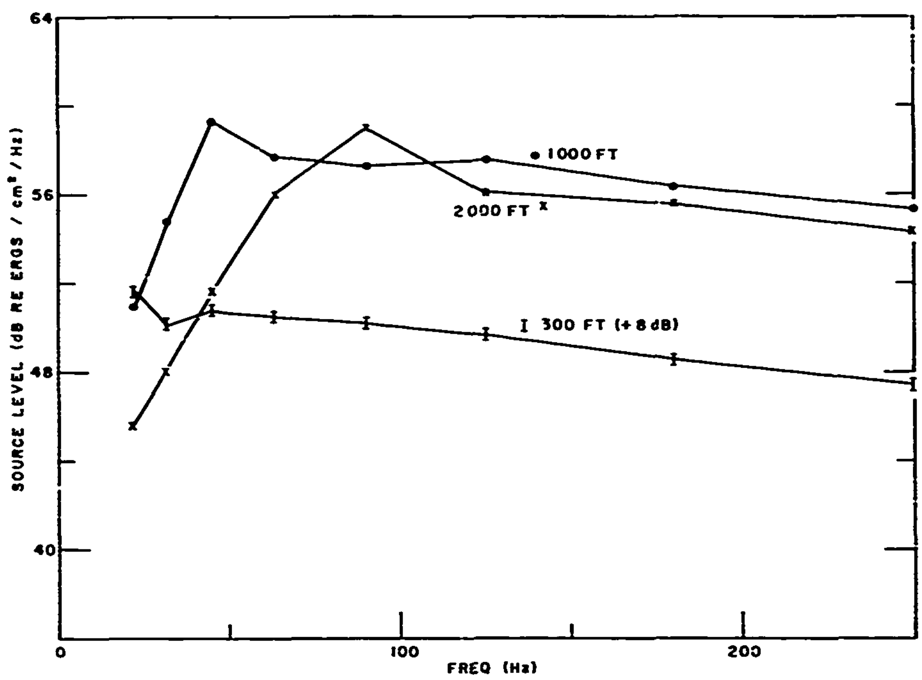

Fig. B-4. Spectral levels for 4 lb TNT.

Figs. B-3 through B8. Calculated and filtered source spectra of explosive shots used in Project APTERYX.

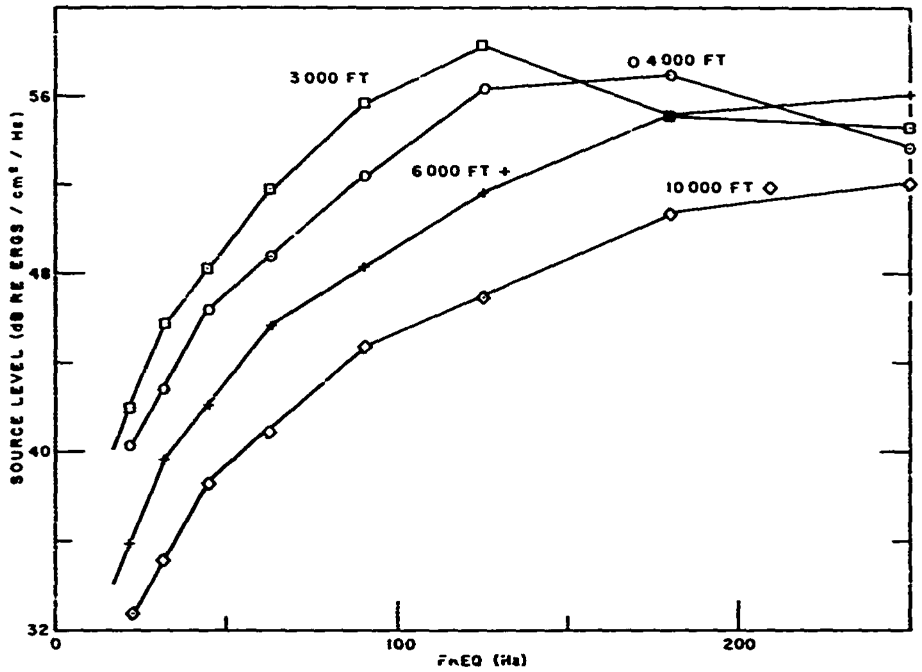

Fig. B-5. Spectral levels for 4 lb TNT.

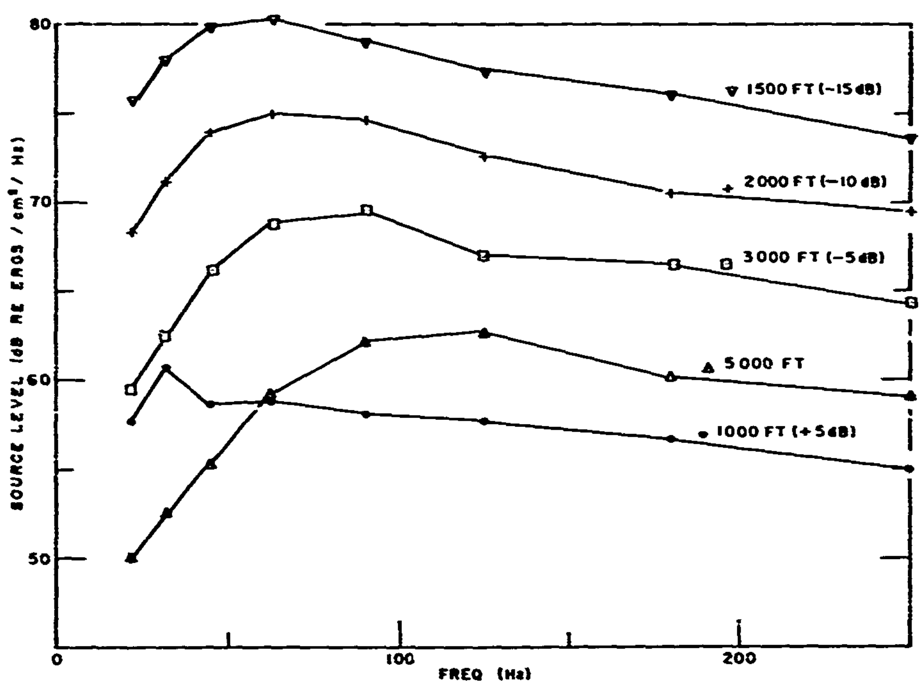

Fig. B-6. Spectral levels for 15 lb TNT.

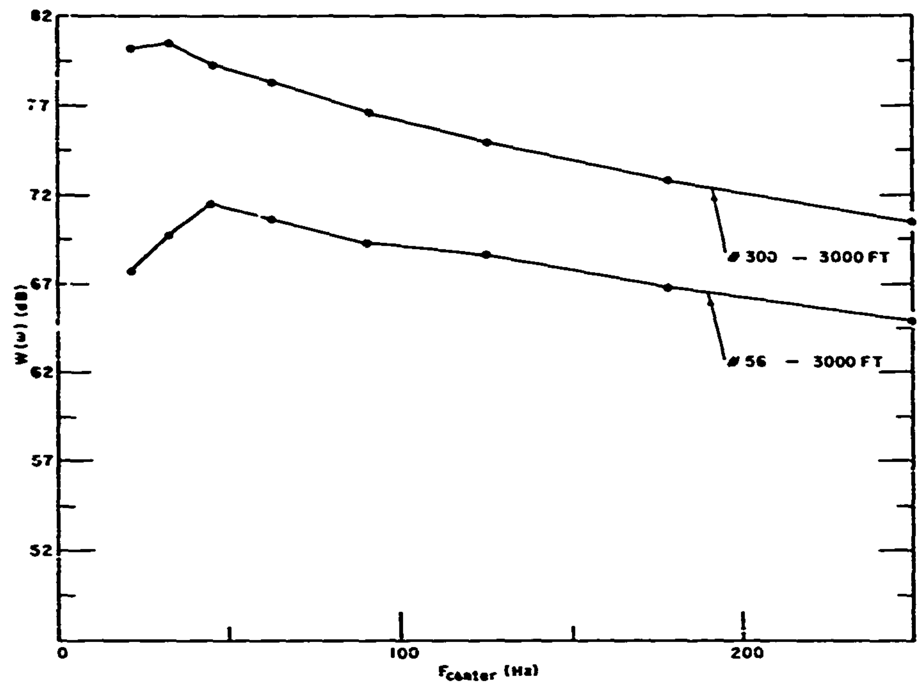

Fig. B-7. Spectral levels for 3000 ft shots.

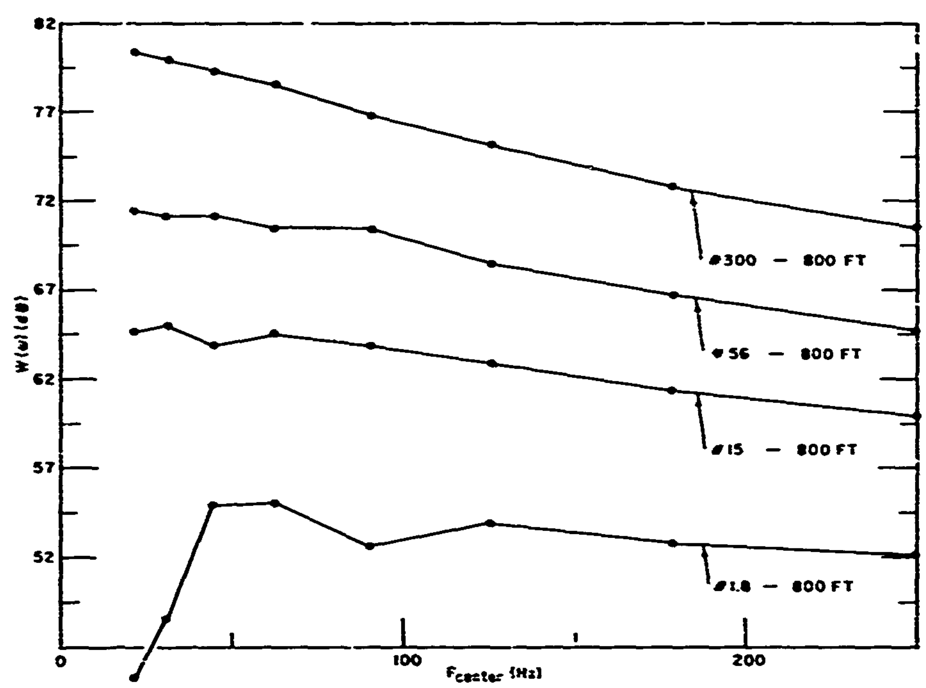

Fig. B-8. Spectral levels for 800 ft shots.

It is well known that it is possible to monitor the depths of shots of kn·wn weight and explosive type over long-range acoustic paths by observation either of the interference spectrum such as that of Fig. B-2 or by autocorrelation of the signal to determine the bubble pulse period τ_1 directly. To a certain extent, however, the process depends on the type of acoustical propagation, and we discuss this for its relevance to the determination of the depth of the shot and thus to the specification of its source spectrum, assuming these to be calibrated.

If the reception consists of a single, purely refracted arrival, the autocorrelation will clearly be that of the source signal waveform shown in Fig. B-1, and will yield the bubble pulse period τ_1 directly. As the number of refracted arrivals increases, however, the autocorrelation measures the relative time delays of the respective arrivals and the contribution of the bubble pulse to the autocorrelation will be masked by the spread of the time delays of the arrivals. However, in the limit of many, randomly spaced arrivals, cancellation occurs in the autocorrelation among the individual arrivals and the bubble pulse contribution reappears in the autocorrelation function. Thus, the acoustic spectrum of many raindrops falling on a tin roof is the "plop" spectrum of an individual drop.[B4]

We have found in a number of experimental programs at Hudson Laboratories that an excellent method for achieving this randomization occurs when the sound is bottom reflected. Figure B-9, for example, is the autocorrelation of reverberation backscattered from bathymetry at a range of 59 miles from a 300-lb depth charge exploded at a depth of .000 ft. In the example, there was sufficient randomization of the contributing arrivals to permit the bubble pulse correlation to appear over the background.

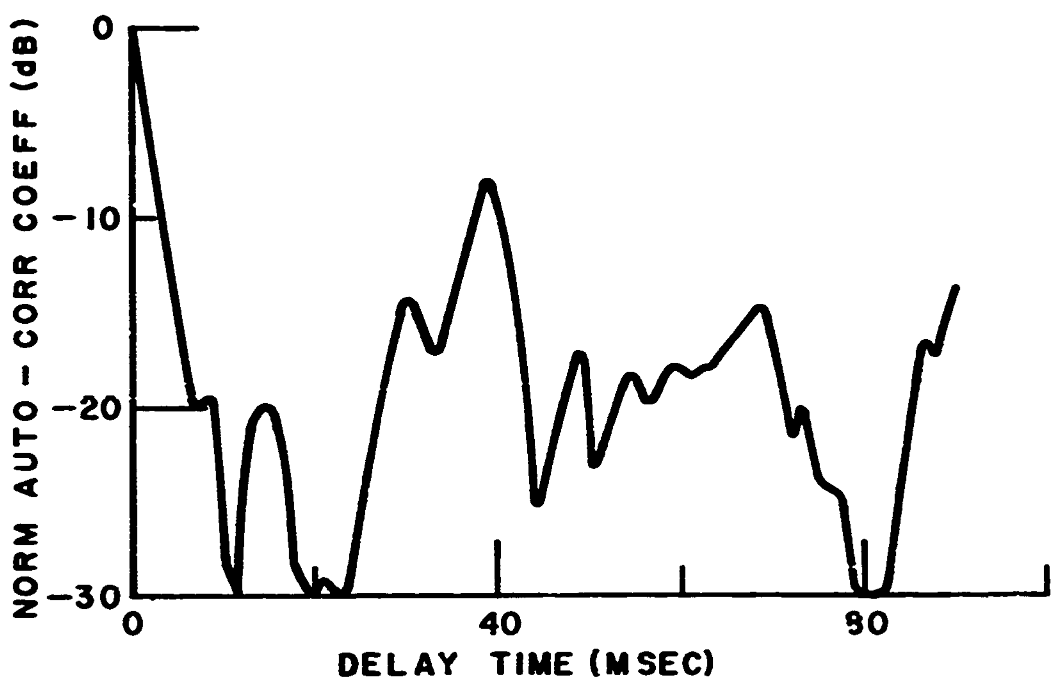

Fig. B-9. Autocorrelation of reverberation from a 300-lb TNT charge explodeá at 3000 ft. The arrival structure has canceled itself and strong correlations of the initial pulse with the bubble pulses appear at the time delays 30 and 39.5 msec.

It is difficult to signal process the source waveform itself in view of its spike character (it is described as having a time-bandwidth product of unity). When many arrivals occur, the superposition of the source waveform results in a signal of broad frequency content that is spread to times of the order of seconds with, usually, bottom-scattered energy filling in the tail of the signal. We have had good success in autocorrelating such signals, using simple Deltic processors which determine correlation by polarity coincidence. By using correlators with storage times for correlation of the order of 0.25 sec and by displaying the successive correlations continuously as synchronous sweeps across an intensity contrast recorder, e.g., a fathometer, the bubble pulse correlation becomes clearly visible and its period can be measured accurately.

Such a display can be used not only to monitor the periods τ_1 for the successive shots, and thus determine the shot depths, but yields additional information about the propagation paths. Thus, if the correlation of the bubble pulse does not appear until the tail of the shot, it indicates that the propagation consists of a limited number of refracted arrivals that are followed by bottom reflections. Contrarily, strong bubble pulse correlations that are coincident with the shot arrival indicate that bottom-reflected paths strongly contribute to the propagation.

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